THE

JOURNAL OF GEOLOGY

OCTOBER-NOVEMBER, 1893.

GEOLOGIC TIME, AS INDICATED BY THE SEDIMENTARY ROCKS OF NORTH AMERICA.*

INTRODUCTION.

OF ALL subjects of speculative geology few are more attractive or more uncertain in positive results than geologic time. The physicists have drawn the lines closer and closer until the geologist is told that he must bring his estimates of the age of the earth within a limit of from ten to thirty millions of years. The geologist masses his observations and replies that more time is required, and suggests to the physicist that there may be an error somewhere in his data or the method of his treatment. The geologist realizes that geologic time cannot be reduced to actual time in decades or centuries; there are too many partially recognized or altogether unknown factors; but he can approximate the relative position of certain formations, and by comparison of their sediments, dimensions, and contained record of life with estimated rates of denudation, sedimentation and organic growth, form a general estimate of their relative time duration. It is my purpose to-day to take up the consideration of the evidence afforded by the sedimentary rocks of our continental area, and largely of a distinct basin of sedimentation, with a view of arriving, if possible, at an approximate time-period for their deposition. Before so doing, I will briefly refer to a few of the opinions that have been held by geologists on geologic

* Vice-Presidential address delivered before Section E, Am. Assc. Adv. Sci., Madison, Wis., August 17, 1893.

time and the age of the earth. Soon after geology emerged from its pre-systematic stage, in the latter part of the eighteenth century, and assumed an independent position among the inductive sciences speculations on the age of the earth began. Dr. James Hutton, the founder of modern physical geology, and the predecessor of Lyell, in advocating the uniformitarian theory, was the first to argue that the rate of destruction of one land area was the means of measuring the duration of others, and that the continents were formed of the ruins of pre-existing continents, but that in our measurement of time such periods were of indefinite duration.[1] It was not, however, until 1830, when Sir Charles Lyell published the results of his profound and philosophic studies of geologic phenomena, that the broad outlines of the law of uniformity, as opposed to the doctrine of geologic catastrophes, was fairly established. This work rendered possible a computation of the age of the earth on the principle that geologic processes were the same in the past as at present. He based his estimate of time on a rate of modification of species of mollusca since the beginning of the "Cambrian period," and divided the geologic series into twelve periods, assigning 20,000,000 years to each for a complete change in their species,—or 240,000,000 years in all. This estimate excluded the "antecedent Laurentian formation."[2]

The hour at our disposal does not permit of mentioning at length the views of other geologists. Dr. Charles Darwin thought that 200,000,000 of years could hardly be considered sufficient for the evolution of organic forms,[3] and Rev. Samuel Haughton assigned 1,280,000,000 of years to pre-Azoic time, and remarked that the globe was habitable, in part at least, for a longer period.[4] At a later date he estimated a minor limit to

[1] Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Globe. Trans. Royal Soc. Edinburgh, Vol. I., 1788, pt. 1, p. 304.

[2] Principles of Geology, 10th Ed., Vol. I., 1867, p. 301.

[3] Origin of Species, American Ed., from 6th Eng. Ed., 1882, p. 286.

[4] Manual of Geology, 3rd Ed., 1871, p. 101.

geologic time of 200,000,000 of years.[1] Dr. James Croll estimated 72,000,000 years for the time duration since the first deposition of sedimentary rocks, while Sir Alfred R. Wallace thought that 28,000,000 years would suffice.[2] Of the value of this estimate he says: "It is not of course supposed that the calculation here given makes any approach to accuracy, but it is believed that it does indicate the order of magnitude of the time required."[3] Dr. Alexander Winchell reduced geologic time still more in his estimate of 3,000,000 years for the whole incrusted age of the world.[4] Later writers, however, do not accept this, as we find Sir Archibald Geikie concluding on the basis of denudation and deposition that the sedimentary rocks would have required 73,000,000 of years for their deposition, if denudation was at the rate of one foot in 730 years; or of 680,000,000 of years if at the slower rate of one foot in 6,800 years.[5] Mr. T. Mellard Reade adopted one foot in 3,000 years as the rate of average denudation throughout geologic time, and obtained a result of 95,000,000 of years as the time that had elapsed since the beginning of Cambrian time.[6] M. A. de Lapparent is one of the few European continental geologists that has written on geologic time. On the basis of mechanical denudation and sedimentation he thinks that from 67,000,000 to 90,000,000 of years would suffice, at the present rate of sedimentation for everything that has been produced since the consolidation of the crust.[7] The two most recent writers who have taken their initial datum point or "geochrone" from the consideration of late Cenozoic or Pleistocene phenomena

[1] Nature, Vol. 18, 1878, pp. 267–268.

[2] Stella Evolution and its Relations to Geological Time, 1889, pp. 48–49.

[3] Island Life, 2d. Ed., 1892, pp. 222–223.

[4] World Life, or Comparative Geology. Chicago, 1883, p. 378.

[5] Presidential Address; report of 62d meeting British Assoc. Adv. Sci., 1892, p. 21.

[6] Measurement of Geological Time. Geol. Mag., Vol. 10, 1893, pp. 99–100.

[7] De la mesure du temps parles phénomènes de sédimentation. Bull. Soc. Geol. France, 3d ser., Vol. 18, 1890, pp. 351–355. La Destinée de la terre férme et durée des temps geologiques. Revue des questions scientifiques, July, 1891. Pamphlet. Bruxelles. Pp. 1–38.

have differed materially in their results. Mr. W J McGee estimated that the mean age of the earth is 15,000 million years, and that 7,000 million had elapsed since the beginning of Paleozoic time.[1] In a subsequent note he modifies this conclusion and gives as a mean estimate 6,000 million years, of which 2,400 million have elapsed since the beginning of the Paleozoic. This is based on a minimum estimate of the age of the earth of 10,000,000 years and a maximum estimate of five million million (5,000,000,000,000) years.[2] Professor Warren Upham concludes that Quartenary time comprises about 100,000 years. He applies Professor Dana's time-ratio, and finds on this basis that the time needed for the earth's stratified rocks and the unfolding of its plant and animal life must be about 100 millions of years.[3]

From the foregoing estimates of geologic time the only conclusion that can be drawn is that the earth is *very old*, and that man's occupation of it is but a day's span as compared with the eons that have elapsed since the first consolidation of the rocks with which the geologist is acquainted.

When I began the preparation of this paper it was my intention to carefully analyze the sedimentary rocks of the entire geological series as exposed upon the North American continent. I soon found, however, that the time at my disposal would make this impracticable, and I decided to take up the history of the deposits that accumulated in Paleozoic time on the western side of our continent, in an area that for convenience I shall call the Cordilleran sea. This was chosen as (1) I was personally acquainted with many of its typical sections; (2) there was a broad and almost uninterrupted sedimentation during Paleozoic time; and (3) there is a prospect for obtaining more satisfactory data as a basis of calculation, since calcareous deposits are in excess of those of mechanical origin.

We will now consider certain points in relation to the growth

[1] American Anthropologist, Vol. 5, 1892, p. 340.

[2] Science, Vol. 21, 1893, p. 309.

[3] Am. Jour. Sci., Vol. 45, 1893, pp. 217–218.

or evolution of the North American continent, as the deposition of mechanical sediments depends to a considerable extent on the character of the adjoining land area, and chemical sedimentation is also influenced by it.

GROWTH OF THE CONTINENT.

The Algonkian sediments were deposited in interior and bordering seas that filled the depressions and extended over the margins of the American continent. From the great thickness of mechanical sediments it was evidently a period of elevated land and rapid denudation. With the close of Algonkian time extensive orographic movements occurred that outlined the subsequent development of the continent. The lines of the Rocky Mountain and Appalachian ranges were determined, and the great basins of sedimentation west of them defined. Subsequent movements have elevated the old and formed new sub-parallel ranges. These movements were often of long duration and also separated by great intervals of time, as is shown by the long-continued base levels of erosion during which the great thickness of calcareous deposits accumulated in the Cordilleran and Appalachian seas. Since Algonkian time the growth of the continent has been by the deposition of sediments in the bordering oceans and interior seas and lakes within the limits of the continental plateau; and it is considered that the relative position of the continental plateau and the deep sea have not materially changed during that period. How much the deposits on the continental border have increased its area is unknown, as at present they are largely concealed beneath the waters of the ocean. During Paleozoic time the two areas of greatest known accumulation were in the Appalachian and Cordilleran seas, where 30,000 feet or more of sediments were deposited. In the Cordilleran sea sedimentation was practically uninterrupted (except during a short interval in middle Ordovician time) until towards the close of Paleozoic time. In the northern Appalachian sea it continued without any marked unconformity, from early Cambrian to the close of Ordovician time, and, south of New York, with

relatively little interruption, until the close of Paleozoic time. Certain minor disturbances occurred along the eastern border of the sea, but they were not of sufficient extent to affect a general conclusion—which is, that the depression of the areas of deposition within the continental platform continued without reversal of the subsidence during Paleozoic time. During Cambrian, and it may be late Algonkian time, the extended interior Mississippian region was practically leveled by denudation, the eroded material being carried into the Cordilleran and Appalachian seas, and, probably, to a sea to the south.

The sedimentation of the Mississippian area in Paleozoic time, between the Appalachian and the Cordilleran seas, was small as compared to that which accumulated in the latter. In Devonian time there does not appear to have been any sedimentation in the western portion of it west of the 94th meridian and east of the Cordilleran sea, and it was slight in the same interval in the Appalachian sea south of the 37th parallel.[1] There is little if any evidence in the sediments of Paleozoic time to show that they were deposited in the deep, open ocean; on the contrary, they were largely accumulated in partially enclosed seas or mediterraneans and on the borders of the continental plateau. The former is particularly true of the sedimentation of the Cordilleran and Appalachian seas and the broad Mississippian sea.

The close of the prolonged period of Paleozic sedimentation was brought about by what Dana has termed the "Appalachian revolution." The topography of the continent was more or less changed, and the conditions of sedimentation that followed were unlike those that preceded. This revolution raised above the sea level a considerable portion of the Cordilleran and the Appalachian sea-beds and also of the Mississippian sea, east of the 96th meridian and north of the 34th parallel.

[1] The non-occurrence of Devonian sediment has not yet been fully explained. It has been suggested that the sea beyond the reach of mechanical sedimentation was too deep for the deposition of calcareous deposits. It is more probable that the sea was shallow and an area of non-deposition, or that its bed was raised to form a low, level land surface at a base level of erosion that was subjected to very slight degradation.

In its effect it may be compared to the Algonkian revolution[1] that preceded the deposition of the Paleozoic sediments.

With the opening of new conditions the sedimentation of Mesozoic time began upon the Atlantic border and over large areas of the western half of the continent with the deposit of mechanical sediments—sands, silts, etc.—during Jura-Trias time. They are of a character that naturally follows a period of disturbance of pre-existing conditions, and the formation of new basins of deposition with more or less elevated adjoining land areas. At its close orographic movements affecting the positions of the beds occurred upon the Pacific and Atlantic coasts, and also, to a more limited degree, throughout the Rocky mountain region. This does not appear to have extended over the plateau region or the central belt between the 97th and 105th meridians.

The Cretaceous formations have their greatest development between the 97th and 112th meridians in Mexico and the United States, in a broad belt which extends from the boundary of the latter to the northwest into the British Possessions as far as the 61st parallel. They were of a marine origin until towards the close of the period when a prolonged orographic movement elevated a large area of the continent above sea level, and locally upturned the Cretaceous strata in the Rocky mountain area. The shoaling of the sea was followed by the formation of great inland lakes, in which fresh water deposits succeeded the marine and estuarian sediments. Over the coastal regions they were of marine origin throughout.

The Tertiary sediments deposited on the Cretaceous are marine on the Atlantic, Gulf of Mexico, and Pacific coasts, and of fresh-water origin in the Rocky mountain and Great Plains areas—where they were deposited in the great inland lakes outlined in the previous period.

[1] The term revolution is used to describe the culmination of a long series of phenomena that finally resulted in a distinctly marked epoch in the evolution of the continent. The "Appalachian revolution" began far back in the Paleozoic, and culminated in the later stages of the Carboniferous and the Algonkian revolution, probably began far back in Algonkian time.

GEOGRAPHIC CONDITIONS ACCOMPANYING THE DEPOSITION OF PALEOZOIC SEDIMENTS IN THE CORDILLERAN SEA.

The assumed area of the Cordilleran or Paleo-Rocky mountain sea includes over 400,000 square miles between the 35th and 55th parallels. To the eastward during lower and middle Cambrian time a land area is thought to have extended from east of the 111th meridian across the continent to the Paleo-Appalachian sea. This land was depressed toward the close of middle Cambrian time, and the Mississippian sea expanded over the wide plateau-like interior region, from the Gulf of Mexico on the south to the Lake Superior region on the north; westward it penetrated among the mountain ridges between the 105th and 111th meridians, laying down the upper Cambrian deposits that are now found in New Mexico, Arizona, eastern Utah, the western half of Colorado, Wyoming, Idaho and Montana, and still farther north into Alberta and British Columbia. During Ordovician, Silurian, Devonian, and Carboniferous time this entire Mississippian region, except portions in Devonian time, appears to have been covered by a relatively shallow sea that was co-extensive with the Appalachian sea and that communicated freely with the Cordilleran sea. During this same age, however, the Rocky mountain area of New Mexico, Colorado, Utah, Wyoming and Montana formed a more or less well-defined boundary of ridges and islands between the Cordilleran and the interior sea up to the 49th parallel. To the north of the latter the conditions appear to have been the same as on the eastern side of the continent, where the Appalachian sea communicated freely with the Mississippian sea. From the data that we now have I think that the Paleozoic (Mississippian) sea extended at times over nearly all of the area subsequently covered by the Cretaceous and the later formations between the Gulf of Mexico and the Arctic ocean. This belt is bounded almost continuously on the east and west by Paleozoic rocks that extend from the Arctic ocean to Mexico, and whether of Cambrian, Ordovician, Silurian or Devonian age they carry essentially the same fauna throughout their extent. In the outcrops of lower strata that rise up

through this Cretaceous area, the Cambrian, Ordovician, and Carboniferous rocks are found encircling the pre-Paleozoic rocks. Instances in which the Archean rocks have been met with immediately beneath the Cretaceous in borings in Dakota and Minnesota are along the eastern border of the area, next to the Archean rocks,—where it is probable that the Cretaceous overlaps the Paleozoic to the Archean.

The western side of the Cordilleran sea seems to have been bounded by a land area that separated it from the Paleozoic sea, which extended through central California and the Pacific border of British Columbia and Vancouver's Island. From the positions of the Carboniferous deposits of California at the present time it appears that this land varied from 100 to 150 miles in width and was practically continuous along the western side of the Cordilleran sea. This view is further strengthened by the fact that the Carboniferous fauna of California has certain characteristics which are not found in the Carboniferous of the Cordilleran area. Our knowledge of conditions north of the 55th parallel is limited by the want of accurate geologic data. If Cambrian and Carboniferous rocks were not deposited in the Mackenzie river basin and also on the eastern side of the area now covered by Cretaceous strata, the inference is that during Cambrian and Carboniferous time there was a land area to the east and north of the northern Cordilleran sea that may have been tributary to the latter.

SOURCE OF SEDIMENTS DEPOSITED IN THE CORDILLERAN SEA.

The sediments deposited in every sea or lake are derived from land areas either by mechanical or chemical denundation.

Mechanical denudation results from the action of the waves and currents along the shore and the agency of rain, frost, snow, ice, wind, heat, etc., on the land. Rain is the most important factor, and the result depends mainly upon its amount and the slope or the gradient of the land. The general average of denudation for the surface of the land areas of the globe, now usually accepted, is one foot in 3,000 years. This varies locally,

according to Sir Archibald Geikie, from one foot in 750 years to one foot in 6,000 years.[1] Of the rate of denudation during Paleozoic time about the Cordilleran sea we know very little, but I think that it was relatively rapid in early Cambrian time and during the deposition of the arenaceous sediments of the Ordovician and Carboniferous. The material forming the argillaceous shales of the Cambrian and Devonian was supplied to the sea more slowly. These conclusions are sustained by the slight change in the character of the faunas where interrupted by the sands and pebbles of the Ordovician and Carboniferous and the marked change between the base and summit of the argillaceous shales. As a whole I think we are justified in assuming a minimum rate of mechanical denudation—of considerably less than one foot in 1,000 years—for the area tributary to the Cordilleran sea.

Chemical denudation is the removal of material taken into solution by water. Mr. T. Mellard Reade has discussed this phase of denudation in an admirable manner.[2] He came to the conclusion, from what was known of the volume of water discharged into the ocean per year, the average amount of material in chemical solution and the area of land surface drained by the rivers, that an average of 100 tons of rocky matter is dissolved per English square mile per annum. Of this he says: "If we allot 50 tons to carbonate of lime, 20 tons to sulphate of lime, 7 to silica, 4 to carbonate of magnesia, 4 to sulphate of magnesia, 1 to peroxide of iron, 8 to chloride of sodium, and 6 to the alkaline carbonates and sulphates we shall probably be as near the truth as present data will allow us to come."[3] By the use of the data given by Mr. John Murray, in a paper on the total annual rainfall on the land of the globe, and the relation of rainfall to the discharge of rivers,[4] I obtain 113 tons as the total

[1] Brit. Assoc. Adv. Sci., Sixty-second Meeting, 1893, p. 21.

[2] Proc. Liverpool Geol. Soc., Vol. III., pt. 3, 1877, pp. 212–235. Chemical Denudation in Relation to Geological Time, 1879, pp. 1–61.

[3] Loc. cit., p. 229.

[4] Scottish Geol. Mag., Vol. III., 1887, pp. 65–77.

amount of matter in solution discharged into the Atlantic basin per annum from each square mile of area drained into it. Of this 49 tons consist of carbonate of lime and 5.5 tons of sulphate and phosphate of lime.[1]

Mechanical Sediments.—With the geographic conditions described as prevailing during Paleozoic time, the source of mechanical sediments later than the Middle Cambrian must have been from the broken area on the eastern side that extended 100 to 200 miles to the eastward and to a much greater extent from the land along the western side of the sea. The enormous deposit of from 10,000 to 20,000 feet of mechanical sediments in early Cambrian time is explained by the assumption of favorable topographic conditions of denudation following the Algonkian revolution and the presence of a land area over the interior portion of the continent, and also, in all probability, between the western side of the Cordilleran sea and the western border of the continent. During this period the conformable pre-fossiliferous strata of the Cambrian accumulated and about 6,000 feet of the lower fossiliferous rocks as they occur in the Eureka district of central Nevada. Following the depression of the continent, which carried down the central area and also introduced the upper Cambrian (Mississippian) sea into the Rocky mountain area of Colorado, etc., there were deposited of mechanical sediments in central Nevada:

Ordovician sands,	500 feet.
Devonian fine argillaceous muds,	2,000 "
Lower Carboniferous sands,	3,000 "
Upper Carboniferous conglomerate and sands,	2,000 "
	7,500 "

making a total of 7,500 feet of mechanical sediments, the remaining portion of the section (15,150 feet) being limestone.

The following table exhibits the relative thickness of

[1] Total amount removed in solution per annum by rivers, 762,587 tons per cubic mile of river water. Total discharge of river water per annum into the Atlantic, 3,947 cubic miles. Area drained, 26,400,000 square miles. Amount of carbonate of lime per annum, 326,710 tons per cubic mile of river water; of sulphate and phosphate of lime, 37.274 tons.

mechanical and chemical deposits in the Cordilleran sea after the middle Cambrian subsidence:

	Wasatch.	Central Nevada.	Southwest Nevada.	Montana.	Alberta.
Mechanical Sediment, - -	10,000	7,500	2,500	1,000	4,600
Chemical Sediment, - -	10,400	15,150	13,000	4,000	15,000
Ratio, - - - - - -	1	2	5	4	3

If an average is taken of the mechanical sediment deposited subsequent to the close of middle Cambrian time, it will be found to be about 5,000 feet for the entire area, which, I think, does away with any necessity to assume an additional hypothetical land area for the source of the mechanical sediment. The fine sand composing the quartzites and the silt forming the shales, as well as the fine conglomerate of later deposits, were derived from the adjoining land areas, and, in all probability, currents swept through from the ocean to the south or north, distributing the mud and sand contributed from the rivers and streams along the shores.

Chemical Sediments.—The present supply of the carbonate of lime, silica, etc., contained in sea-water is derived from waters poured into the sea by rivers and streams. The Cordilleran sea undoubtedly received a large contribution from the adjoining land areas, but a considerable amount was possibly derived from an oceanic current that circulated through it as the southern equatorial current of the Atlantic now sweeps through the Caribbean. From the vast deposits of carbonate of lime it might be assumed, *a priori*, that the waters of a Mississippi or Amazon were poured into it, but there is not any evidence of the existence of such a river, although the tributary area may have been very large in Cambrian and Carboniferous time, if the drainage of the country west of Hudson's Bay was to the westward.

Conditions of Deposition.—With free communication into the open ocean on the south, and probably on the north, during most of Paleozoic time strong currents must have circulated through the Cordilleran sea. The broad distribution of

mechanical sediments of a uniform character clearly shows this to have been the case, especially in pre-Silurian (Ordovician) time. The present known distribution of the mechanical sediments indicate that they were mainly brought into the sea from the west,[1] although a vast amount was derived from the land on the eastern side in pre-Ordovician time. They were quite evenly distributed over the sea bed, except where local accumulations of silt and sand occurred near the larger sources of supply, or in the direction of powerful currents within the sea.

The conditions of the deposition of the carbonate of lime are less clearly understood than those governing mechanical sediments, and I shall enter upon the discussion of them at considerable length. There are three methods by which it usually is considered that it may be deposited: 1. Agency of organisms; 2. Chemical precipitation; 3. By mechanical methods.

It is the general opinion of geologists that limestone rocks are the result almost entirely of the consolidation of lime removed from the sea water through the agency of life, and that they consist of the remains of foraminifera, crinoids, corals, etc., or their fragments, embedded in a more or less crystalline matrix resulting from subsequent alteration of the original deposits. This, however, has been seriously questioned. Sorby, in giving his general conclusions of an extensive microscopic examination of limestones, states that:

Even if it were possible to study in a detached state the finer granular particles which constitute so large a part of many limestone formations, it would usually be impossible to say whether they had been derived from organisms which can decay down into granules, or from other organisms which can only be worn down into granules, or from ground-down older limestone, or, in some cases, from carbonate of lime deposited chemically as granules. . . . . The shape and character of the identifiable fragments do, indeed, *prove* that much of this must have been derived from the decayed and worn-down calcareous organisms;

[1] Geol. Expl. Fortieth Parallel, Vol. I., 1878, p. 247.

and very often we may reasonably *infer* that the greater part, if not the whole, was so derived; but, at the same time, it is impossible to *prove*, from the structure of the rock, whether some or how much was derived from limestones or earlier date, or was deposited chemically, as some certainly must have been.[1]

In their memoir on coral reefs and other carbonate of lime formations in modern seas, Messrs. Murray and Irvine show that temperature of the water has a controlling influence upon the abundance of species and individuals of lime-secreting organisms; high temperature is more favorable to abundant secretions of carbonate of lime than high salinity.[2]

Taking the samples of deep sea deposits collected by the Challenger as a guide, the average percentage of carbonate of lime in the whole of the deposit covering the floor of the ocean is 36.83; of this it is estimated that fully 90 per cent. is derived from pelagic organisms that have fallen from the surface water, the remainder of the carbonate of lime having been secreted by organisms that laid on, or were attached to, the bottom. The estimated area of the various kinds of deposits, the average depth, and the average percentage of carbonate of lime to each are shown in the following table:

TABLE showing the Estimated Area, Mean Depth, and Mean Percentage of $CaCO_3$, of the different Deposits.

Deposit.		Area square miles.	Mean depth in fathoms.	Mean per ct. of $CaCO_3$.
Oceanic Oozes and Clays	Red clay,	50,289,600	2727	6.70
	Radiolarian ooze,	2,790,400	2894	4.01
	Diatom ooze,	10,420,600	1477	22.96
	Globigerina ooze,	47,752,500	1996	64.53
	Pteropod ooze	887,100	1118	79.26
Terrigenous Deposits	Coral sands and muds,	3,219,800	710	86.41
	Other terrigenous deposits, blue mud, etc.	27,899,300	1016	19.20

Loc. cit., p. 82.

"We have little knowledge as to the thickness of these deposits, still such as we have goes to show that in these organic cal-

[1] Quart. Jour. Geol. Soc. London, Vol. 35, 1879, pp. 61–92.

[2] Proc. Roy. Soc. Edinburgh, Vol. 17, 1890, p. 81.

careous oozes and muds, we have a vast formation greatly exceeding in bulk and extent the coral reefs of tropical seas; they are most widely distributed in equatorial regions, but some patches of Globigerina ooze are to be found even within the Arctic circle in the course of the gulf stream."[1]

The percentage of carbonate of lime contained in deposits accumulating at different depths, as obtained from 231 samples collected by the Challenger, is shown in the following tabulation:

14	cases	under	500		fathoms,	m. p. c.	86.04
7	"	"	500	to 1000	"	"	66.86
24	"	"	1000	to 1500	"	"	70.87
42	"	"	1500	to 2000	"	"	69.55
68	"	"	2000	to 2500	"	"	46.73
65	"	"	2500	to 3000	"	"	17.36
8	"	"	3000	to 3500	"	"	0.88
2	"	"	3500	to 4000	"	"	0.00
1	"	"	4000		"	"	trace.

The fourteen samples under 500 fathoms are chiefly coral muds and sands, and the seven samples from 500 to 1000 fathoms contain a considerable quantity of mineral particles from continents or volcanic islands. In all the depths greater than 1000 fathoms the carbonate of lime is mostly derived from the shells of pelagic organisms that have fallen from the surface waters, and it will be noticed that these wholly disappear from the greater depths.[2]

By a series of experiments Messrs. Murray and Irvine found: "That although sea water under certain conditions may take up a considerable quantity of carbonate of lime in solution, yet it is unable permanently to retain in solution more than is usually found to be present in sea water, and it is owing to this that the amount of carbonate of lime is so constantly low. The reaction between organic matter and the sulphates present in sea water (to which we have referred) tends also to keep the amount of carbonate of lime in solution at about one-half (0.12 grms.) of what it might contain (0.28 grms. per litre). This peculiarity of sea water, in taking up a large amount of amorphous carbon-

[1] Loc. cit., pp. 82–83.

[2] Loc. cit., p. 84.

ate of lime and throwing it out in the crystalline form, accounts for the filling up of the interstices of massive coral with crystalline carbonate in coral islands and other calcareous formations, so that all traces may ultimately be lost of the original organic structure."[1]

The authors explain the disappearance of shells and lime deposits in the greater depths of the ocean by their being dissolved by the carbonic acid in the water, which is present in larger quantity at great depths and also is produced by the decomposition of the animal matter of the shell and of the various organisms living in the water and on the bottom. They conclude that:

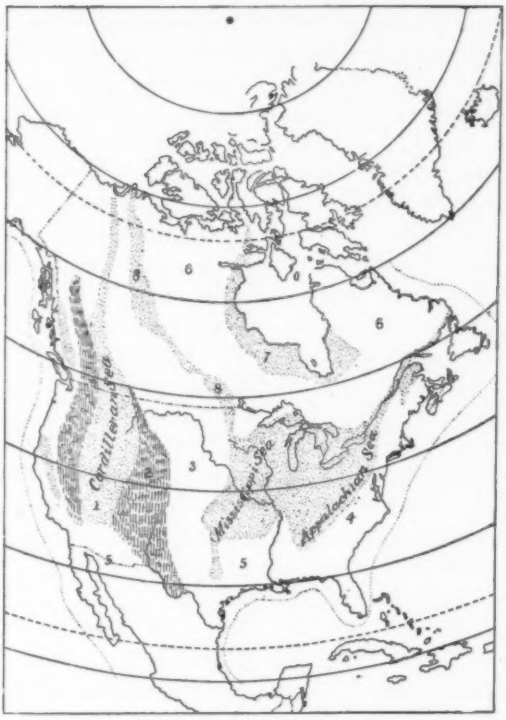
On the whole, however, the quantity of carbonate of lime that is secreted by animals must exceed what is re-dissolved by the action of sea water, and at the present time there is a vast accumulation of the carbonate of lime going on in the ocean. It has been the same in the past, for with a few insignificant exceptions all the carbonate of lime in the geological series of rocks has been secreted from sea water, and owes its origin to organisms in the same way as the carbon of the carboniferous formations; the extent of these deposits appears to have increased from the earliest down to the present geological period.[2]

In their report on deep sea deposits, collected by the Challenger Expedition, Messrs. Murray and Renard state that the chemical products formed in situ on the floor of the ocean nearly all originate in a sort of broth or ooze, in which the sea water is but slowly renewed. Many of them appear to be formed at the surface of the deposit—at the line separating the ooze from the superincumbent water, where oxidation takes place. In the deeper layers of the deposit a reduction of the higher oxides frequently occurs, and at the surface of the mud or ooze there are many living animals, as well as the dead remains of surface plants and animals.[3]

[1] Loc. cit., pp. 94–95.

[2] Loc. cit., p. 100.

[3] Report on the Scientific Results of the Voyage of M. M. S. Challenger. Deep-Sea Deposits, 1891, p. 337.



DESCRIPTION OF MAP.

On the map the hypothetical areas of the Cordilleran, Mississippian and Appalachian seas are clearly indicated. The land area west of the Cordilleran sea is numbered No. 1. The Californian sea and the area of Paleozoic deposits of western British Columbia No. 10. The northern extension of the Cordilleran sea (No. 9) is continued as the Paleozoic-devonian sea to the Arctic ocean. The early Cambrian land area (No. 2) east of the Cordilleran sea must have been more or less covered by water during later Paleozoic time. The area now covered by Mesozoic deposits, indicated by No. 3, was presumably covered by the westward and northward extension of the Paleozoic-Mississippian sea. The area east of the Appalachian sea is indicated by No. 4; and the supposed land barrier between the Hudson Bay and the Mississippian sea by No. 6; it is not improbable that during Ordovician or Silurian time a sea may have connected the two latter seas. The region to the south, indicated by No. 5, is supposed to have been covered by the southward extension of the Appalachian, Mississippian and Cordilleran seas. It is now covered by deposits of Mesozoic and Cenozoic seas.

A more detailed description of the map can be gained from the section on the growth of the continent and on the geographic conditions accompanying the different depositions of Paleozoic sediments in the Cordilleran sea.

They also conclude that practically all the carbon of marine organisms must ultimately be resolved into carbonic acid, the quantity of that acid produced in this way must be enormous, and cannot but exert a great solvent action not only on the dead calcareous structure, but also on the minerals in the muds on the floor of the ocean.[1] Of the effect of this destructive action, they say: "In all cases, however, calcareous structures of all kinds are slowly removed from the bottom of the ocean on the death of the organisms, unless rapidly covered up by the accumulating deposits, and in this way protected to a certain extent from the solvent action of the sea-water. It is evident from the Challenger investigations that whole classes of animals with hard calcareous shells and skeletons, remains of which one might suppose would be preserved in modern deposits, are not there represented; although they are now living in immense numbers in the surface waters or on the deposits at the bottom in some regions, yet all traces of them have been removed by solution. A similar removal of calcareous organic structures has undoubtedly taken place in the marine formations of past geologic ages.[2]

From the preceding statements it is evident that initially the greater part of the carbonate of lime is taken from the sea water by organic agency, but in the working over of this material in the chemical laboratory at the bottom of the sea a considerable portion is taken up by the sea water as amorphous carbonate of lime and thrown out in the crystalline form to form the matrix of the undissolved shells, etc.[3]

Mr. Bailey Willis has recently studied the question of the deposition of carbonate of lime, and states that "chemists describe two conditions under which bicarbonate of lime may be decomposed into neutral carbonate and carbonic acid: 1st, by diminution of the tension of the carbonic acid in the atmosphere; 2nd, by agitation of the solution."

[1] Loc. cit., p. 255.

[2] Loc. cit., p. 277. In this connection I wish to ask the student to read Messrs. Murray and Irvine's remarks on pp. 97-99, Proc. Roy. Soc., Edinburgh, Vol. 17, 1890.

[3] Proc. Roy. Soc., Edinburgh, Vol. 17, 1890, pp. 94-95.

"Theoretically either one of three things may occur to the neutral carbonate of lime, if it be thrown out of solution by either one of these processes. The carbonate may be redissolved, deposited as a calcareous mud, or built into organic structure." He studied some recent limestone deposited in the Everglades of southern Florida and found it to be formed of fragments of shells embedded in calcite. He states that, "Under the microscope the unaltered structure of the organic fragments is strikingly different from that of the coarse holocrystalline matrix, in which it is apparent that the crystals developed in place. Were this a limestone of some past geologic period it would be concluded, on the evidence of the crystalline texture of some parts of it, that it had been metamorphosed, and that the organic remains now visible had escaped the process which altered the matrix. But the observed conditions of its formation preclude the hypothesis of secondary crystallization."[1] Apparently the crystalline matrix is one primary product, and the calcareous mud is another, which being precipitated in the solution remains an incoherent sediment.

I think we may accept the conclusion that the deposition of carbonate of lime is by both organic agency and chemical precipitation. It is not necessary to speak of deposition by mechanical methods except in relation to the deposition of chemically derived granules. This probably takes place, and may be a very important factor in the formation of limestones in seas receiving a large supply of calcium from the land. Calcareous conglomerates do not enter as a prominent deposit in the Cordilleran area.

There is no evidence in the marine, geologic formations of this continent that they were deposited in the deep sea; on the contrary they are unlike such deposits and bear positive evidence of having been laid down in relatively shallow waters. Limestones with ripple-marks and sun cracks occur, and beds of ripple-marked sandstones alternate with shales and limestones. The more massive limestones, however, appear to have accumulated in deeper water. The conditions in the Cordilleran sea

[1] See Mr. Willis' article in Journal of Geology, Chicago, September, 1893.

were, I think, more favorable for rapid deposition than in the deep open ocean, but probably not as favorable as about coral reefs and islands. The limestones, and often the contained fossils, clearly indicate the presence of many of the same conditions of deposition as described by the authors I have quoted. More or less decomposed shells occur in nearly every limestone and a large proportion of limestone ; especially the non-metamorphic marbles clearly show that they were deposited under the influence of the agencies at work in the laboratory of the sea. Willis states that this occurs in the shallow waters of the Everglades of Florida, and there is no *a priori* reason why it did not occur throughout geologic time,—on the contrary, there is no doubt that it did.

Rate of deposit in former times.—It has frequently been assumed that in the earlier epochs the conditions were more favorable for rapid denudation, and in consequence thereof the transportation and deposition of sediment was greater. Professor Prestwich considers[1] that prior to the sedimentary rocks the land surface consisted of crystalline or igneous rocks subject to rapid decomposition owing to the composition of the atmosphere and to their inherent tendency to decay. They must have yielded to wear and removal with a facility unknown amongst mechanically formed and detrital strata where erosion operates. He thus accounts for one of the factors that gave the large dimensions and thicknesses of the earlier formations. Mr. Wallace thinks that geological change was probably greater in very remote times,[2] stating that all tellurac action increases as we go back into the past time, and that all the forces that have brought about geological phenomena were greater.[3]

[1] Geology, Vol. 1, 1886, pp. 60-61.

[2] Island Life, 2nd Ed., 1892, pp. 223-224.

[3] Sir William Thompson (Lord Kelvin), inferred from his investigations upon the cooling of the earth, that the general climate cannot be sensibly affected by conducted heat at any time more than 10,000 years after the commencement of the superficial solidification. Treatise on Natural Philosophy, Cambridge, 1883, Vol. 1, pt. 2, p. 478. Of the degree of the sun's heat we know so little that conjectures in relation to it have little force against the conditions indicated by the sedimentary rocks and their contained organic remains.

Dr. Woodward says, on the opposite view, that in the earliest geological periods each bed of sand, clay, limestone, etc., had actually to be formed, and that later deposits had the older sedimentary ones to furnish material, and, therefore, the newer deposits were laid down more rapidly.[1] This does not impress me strongly; but from my experience among the Paleozoic rocks I agree with Sir A. Geikie, that "We can see no proof whatever, nor ever any evidence which suggests that on the whole the rate of waste and sedimentation was more rapid during Mesozoic and Paleozoic time than it is to-day."[2]

Professor Huxley, in his presidential address to the Geological Society of London in 1870, treats of the distribution of animals and says of his hypothesis that it "requires no supposition that the rate of change in organic life has been either greater or less in ancient times than it is now; nor any assumption, either physical or biological, which has not its justification in analogous phenomena of existing nature."[3]

In the Grand Cañon of the Colorado, Arizona, there are 11,950 feet of strata of Algonkian age extending unconformably beneath the Cambrian. There is nothing in this section to indicate that the conditions of deposition were unlike those of the strata of Paleozoic and Mesozoic time. The sandstones, shales, and limestones are identical in appearance and characteristics with those of the latter epoch. The deposition of sulphate of lime and gypsum occurred abundantly in the upper portions of the series, and salt is collected by the Indians from the deposits formed by the saline waters issuing from the sandstone 8,000 feet below the summit of the series. The sandstone and shales were deposited in thin, even laminæ and layers, and the sun cracks and ripple marks give evidence of slow, uniform deposition. In the upper part of Chuar terrane there are 235 feet of limestone. And in one of the layers of limestone, 2,700 feet below the summit of the Chuar terrane, I find abundant evidence of the pres-

[1] Geol. England and Wales, 2nd Ed., 1887, p. 23.

[2] Rept. Sixty-second Meeting Brit. Assoc. Adv. Sci., 1892, p. 19.

[3] Quart. Jour. Geol. Soc., Vol. 26, 1870, p. lxiii.

ence of spiculæ of sponges, and what appear to be worn fragments of some small fossils. There is absolutely nothing to indicate more rapid denudation and corresponding deposition in this early pre-Cambrian series than we find in the Paleozoic, Mesozoic or Cenozoic formations.

PALEOZOIC SEDIMENTS OF THE CORDILLERAN SEA.

The great sections of sedimentary rocks in Arizona, Nevada, Utah, Montana, and in Alberta, B. A., all bear evidence that the sediments of which they are built up were deposited in a connected and continuous sea that extended from the vicinity of the 34th parallel, on the south, to the Arctic ocean on the north. Judging from the data now available, the width of this sea varied from 300 miles in Nevada to 500 miles on the line of the 40th parallel, and, with interruptions by mountain ridges, to 250 miles on the 49th parallel. It appears to have narrowed to the north in Alberta, British Columbia. Roughly computed, it covered south of the 55th parallel 400,000 square miles exclusive of any extension westward into northern-central California and southwestern Oregon and to the eastward over the area subsequently covered by the great interior Cretaceous sea. There is also an addition that might be made to allow for the contraction of the area by the later north-and-south faults and thrusts. Dr. G. M. Dawson estimates that in the Alberta and British Columbia area the width of the zone of the Paleozoic rocks has probably been reduced one-half by the folding and faulting, or from 200 to 100 miles.[1] This area assumed for the Cordilleran sea is on this account probably one-half less than it was before the Appalachian revolution.

The Wasatch section, on the eastern side of the area under consideration, has 30,000 feet of strata, of which 10,400 feet are limestone.[2] Further to the west, 250 miles W.S.W., at Eureka, Nevada, there 30,000 feet of strata in the entire section, and of this amount 19,000 feet are referred to limestone.[3] In the Pahranagat range and vicinity, 200 miles south of the Eureka section,[4]

[1] Bull. Geol. Soc. Am., Vol. 2, 1891, p. 176.

[2] Geol. Expl. Fortieth Parallel, Vol. 1, 1878, pp. 155-156.

[3] Mon. U. S. Geol. Survey, Vol. 20, 1892, p. 178.

[4] Loc. cit. pp. 186-200.

the limestones of the Paleozoic measure over 13,000 feet in a section of 13,500 feet. This section includes only 350 feet of the upper beds of the lower quartzite series, which is upwards of 11,000 feet in thickness in the Schell Creek range of eastern Nevada.[1]

On the eastern side of the area, in Montana, 300 miles north of the Wasatch section of Utah, the deposit of Paleozoic sediment is less in volume. Dr. A. C. Peale's section gives 3,800 feet of limestone in 5,000 feet of strata.[2] This does not include the 6,000 feet or more of sediments that occur below the fossiliferous Cambrian. I believe that the Paleozoic section will be found to be considerably thicker to the westward in Idaho. Continuing to the north 450 miles, the sections measured by Mr. R. G. McConnell, give 29,000 feet of Paleozoic strata, including 14,000 feet of limestone[3]. In a "Note on the Geological Structure of the Selkirk Range," Dr. Geo. M. Dawson describes a section containing upwards of 40,000 feet of mechanical sediments, which he refers largely to the Cambrian[4].

The Paleozoic limestones extend to the north, on the line of the eastern Rocky Mountains, to the Arctic ocean. In latitude 55° to 60° N. the Devonian limestones are over 2,500 feet in thickness, and there other still lower Paleozoic rocks that have not yet been studied in detail. The Devonian limestones extend 700 miles in the valley of the Mackenzie, from Great Slave Lake to below Fort Good Hope.[5] No Carboniferous limestones have been described from this region.

Tabulating the sections south from the 55th parallel and allowing for a great thinning out of the sediments in Idaho and Montana, we obtain an approximate general average of 21,000 feet of strata, of which 6,000 feet are limestone over an area estimated to include 400,000 square miles. Each square mile

[1] Geol. and Geog. Surveys West of 100th Merid., Vol. 3; Geology, 1875, p. 167.

[2] Author's manuscript.

[3] Geol. and Nat. Hist. Sur. Canada; Am. Rep., 1866, pp. 17, D–30 D.

[4] Bull. Geo. Soc. Am. Vol. 2, 1891, p. 168.

[5] Rept. Expl. Yukon and Mackenzie Rivers Basins, N. W. Terr. Geolo. & Nat. Hist. Sur. Canada, Vol. 4 (1888–'89), 1890, pp. 13 D–18 D.

includes 27,878,400 cubic feet of limestone for each foot in thickness and 167,270,400,000 cubic feet for a thickness of 6,000 feet, which, with an average of 12.5 cubic feet to ton, gives 13,381,632,000 tons of limestone and impurities per square mile. The result of ten analyses of clear limestones within the central portion of area gives an average of 76.5 per cent. of carbonate of lime.[1] Taking 75 per cent. as the proportion of pure carbonate of lime (after deducting 50 per cent. to allow for arenaceous and argillaceous material in partings of strata, etc.), there remain 5,018,112,000 tons per square mile; multiplying this by 400,000 the result gives the number of tons of carbonate of lime that were deposited in what we know of the Cordilleran sea in Paleozoic time, or 2,007,244,800,000,000 tons, or two billion million tons in round numbers.

The following mode of presentation of the above was suggested by Mr. Willis:

> In order to proceed with a calculation of the period required to form this thickness of 15,000 feet of mechanical sediment plus 6,000 feet of calcareous sediment, it is necessary, 1st, to compute the cubic volumes of the sediments; 2d, to estimate the area from which they were derived; and, 3d, to divide the cubic contents of the sediments by this land area. The result thus obtained represents the depth of erosion required to furnish the whole deposit, from which we may estimate the time under different assumptions of the rate of erosion.
>
> But if we express amounts in cubic feet or tons the figures pass all comprehension; therefore, to simplify the statement, it is well to use a mile-foot as the unit of volume, that is, the volume of one mile square and one foot thick. (1 mile-foot=.79 Kilometre-metres). This is equal to 223,000 tons, if 12½ cubic feet of limestone equal one ton.
>
> Thus stated mechanical sediments covering 400,000 square miles and 15,000 feet thick contain 6 billion mile-feet (4,740 million Kilometre-metres); and calcareous sediments covering the same area and 6,000 feet thick correspond to 2 billion 4 hundred million mile-feet (1,896 million Kilometre-metres). In the calcareous sediments a liberal allowance of one-half may be made for arenaceous and argillaceous matter in the limestone and partings, and analyses of ten clear limestones within the central part of the area give a little more than 75 per cent. of carbonate of lime. Applying these reductions we get 900 million mile feet (711 million Kilometre-metres) of pure carbonate of lime.

DURATION OF PALEOZOIC TIME IN THE CORDILLERAN AREA.

Estimates from Mechanical Sedimentation.—The land area tributary to the Cordilleran sea was larger before the depression of

[1] Geol. Expl. Fortieth Par. Vol. 2; Mon. U. S. Geol. Survey, Vol. 20.

the continent, towards the close of middle Cambrian time than during subsequent Paleozoic time. It included a portion of the region to the eastward and probably a belt of land extending well towards the Pacific coast of the continental plateau. The interior (Mississippian) region, west of the 90th meridian, probably drained into the sea to the south, forming a Cambrian Mississippi river prior to middle Cambrian time. This limits the Cambrian drainage into the Cordilleran sea to an area estimated at 1,600,000 square miles. The average thickness of mechanical sediments deposited before upper Cambrian time is estimated at from 10,000 to 15,000 feet. Taking the minimum of 10,000 feet and the assumed drainage area of 1,600,000 square miles and the rate of denudation at one foot in 1,000 years, it would have required 2,500,000 years to carry to the sea and distribute the 10,000 feet of sediment. This means the deposition of .048 of an inch per year, which is very small if the supposed conditions of denudation and transportation were as favorable as the character and mode of occurrence of the sediments indicate. If one-fourth of an inch per year is assumed as the rate of deposition, the 10,000 feet of sediment would have accumulated in 480,000 years or, in round numbers, in 500,000 years, which increases the rate of denudation to one foot in 200 years.[1]

CAMBRIAN MECHANICAL SEDIMENTS.

Rate of erosion over land area of 1,600,000 square miles.	Time in years for erosion of 2,500 feet.	Rate of deposition over sea area of 400,000 square miles for strata 10,000 feet thick.
1 foot in 3,000 years, - -	7,500,000	1 foot in 750 years, or .016 inch per annum.
1 foot in 1,000 years, - -	2,500,000	1 foot in 250 years, or .048 inch per annum.
1 foot in 200 years - - -	500,000	1 foot in 50 years, or .24 inch per annum.

In view of the evidence of rapid accumulation contained in the strata themselves the most rapid rate of deposition here stated, namely, .24 inch per annum, is considered as the most probable.

[1] By Mr. Willis' method (*ante*, p. 662, foot note) the mechanical sediments of the Paleozoic age for the area under consideration corresponds to 6 billion mile-feet.

In dealing with the post-middle Cambrian mechanical sediments we have a somewhat different problem, but, as a whole, rapid deposition is indicated. For instance, the Eureka quartzite of the upper Ordovician is a bed of sandstone, varying from 200 to 400 feet in thickness, distributed over a wide area,—perhaps 50,000 square miles. It is made almost entirely of a white, clean sand that was deposited in so short an interval that the Trenton fauna in the limestone beneath it and in the limestones above it is essentially the same. The sand appears to have been swept rapidly into the sea and distributed by strong currents. The same is true of the 3,000 feet of the lower Carboniferous sand and the 2,000 feet in the upper portion of the Carboniferous, while the shales of the upper Devonian accumulated more slowly. In this connection we must bear in mind that during the long periods in which the calcareous sediments forming the limestones were being deposited, the tributary land areas were in all probability base-levels of erosion, and chemical denudation was preparing a great supply of mechanical material that, on the raising of the land, was rapidly swept into the sea and distributed. In this manner the time period of actual mechanical denudation was materially shortened, yet, on account of the manifestly slower deposition of the Devonian shales, the rate of denudation should be assumed as less than during Cambrian time.

In post-Cambrian time the area of the land surface was materially reduced by subsidence, which did not, however, greatly extend the Cordilleran sea, and it may fairly be estimated at 600,000 square miles. The depth of mechanical sediments already estimated is 5,000 feet, and their volume at two billion mile-feet. Dividing the volume by the area of erosion we get 3,300 feet as the depth of erosion required.

Again, applying different rates of erosion, with allowance for slow progress of degradation during Devonian time, we have:

Of this total the greater part, namely, two-thirds or 4 billion mile-feet, are of Cambrian age. Dividing this volume by the land area just given, 1,600,000 square miles, we get 2,500 feet as the depth of erosion during the formation of the Cambrian mechanical sediments. Assuming different rates of erosion we may obtain times differing as follows:

POST-CAMBRIAN MECHANICAL SEDIMENTS.

Rate of erosion over land area of 600,000 square miles.	Time required for removal of 3,300 feet.	Rate of deposition in sea of 400,000 square miles, for 5,000 feet of strata.
1 foot in 3,000 years, - -	9,900,000 years	1 foot in 1,980 years, or .006 inch per annum.
1 foot in 1,000 years, - -	3,300,000 years	1 foot in 660 years, or .09 inch per annum.
1 foot in 200 years, - - -	660,000 years	1 foot in 132 years, or .18 inch per annum.

The rate of one foot in 200 years is assumed as the most probable and 660,000 years as the time required for the removal and deposition of the 5,000 feet of post-Cambrian mechanical sediments.

There is one factor that may need to be taken into consideration in estimating the time duration of the deposition of the mechanical sediments of the Cambrian and pre-Cambrian of the northern portion of the Cordilleran sea that would materially lengthen the period. Dr. George M. Dawson describes the Nisconlith series, especially in the Selkirk range of British Columbia, as composed of "blackish argillite-schists and phyllites, generally calcareous, with some beds of limestone and quartzite, 15,000 feet."[1] It is correlated with the Bow River series, which contains, in the upper portion, the lower Cambrian fauna. The presence of these calcareous beds indicates a slower rate of deposition than we have estimated for the lower portion of the Cambrian series over the greater part of the Cordilleran sea; but as yet the correlation with the sediments of the Cordilleran sea is not sufficiently well established to warrant our allowing a greater time period to the Cambrian on this account.

Estimates from Chemical Sedimentation.—We have estimated that the Paleozoic sediments of the Cordilleran sea contain 2,007,244,800 million tons (900 million mile-feet) of carbonate of lime, which was derived by organic or chemical agencies from the sea water to which it was contributed by the land. If oceanic circulation could be excluded from the problem we might pro-

[1] Bull. Geol. Soc. Amer., Vol. II., 1891, p. 168.

ceed directly to estimate the time required to obtain this amount of lime from the land area tributary to the Cordilleran sea. It may be well to make such an estimate on the basis that the area of denudation tributary to the Cordilleran sea in post-middle Cambrian time had 600,000 square miles from which 30,000,000 tons of carbonate of lime and 12,000,000 tons of sulphate of lime were derived per annum,[1] if we assume T. Mellard Reade's rate of erosion—of 50 tons of carbonate of lime and 20 tons of sulphate of lime per square mile per annum. If all of the 42,000,000 tons (equal to 18.8 mile-feet) per annum were deposited within the limits of the Cordilleran sea, it would have taken 47,790,000 years for the accumulation of the carbonate of lime now estimated to have been deposited in the Cordilleran sea. Such a result is manifestly a maximum based on the consideration of one set of phenomena. In addition, however, to this supply of calcium the geographic conditions appear to have been favorable to the free circulation of oceanic currents through the Cordilleran sea, and the temperature was favorable to extensive evaporation and to the development of organic life, as shown by the occurrence of corals in the middle and upper portions of the Paleozoic, from the Mackenzie river basin on the north to southern Nevada on the south. These conditions would reduce the time necessary for the deposition of the carbonate line.

Ocean water of the present time contains in solution 151.025000 tons of solid matter per cubic mile, which is divided among various salts. A comparison of the matter in the sea and river water shows that the sea contains 3.85 parts of magnesium to one of calcium, and river water contains three parts of calcium to one of magnesium. The silica and alumina of the river water disappears in sea water, while the sodium is accumulated. It is from these considerations and the fact that limestones are

[1] Messrs. Murray and Renard consider that organisms have the power of secreting the carbonate of lime from the sulphate of lime contained in the sea water by chemical reaction. For an account of the chemical action that takes place in the sea water, see report of the Deep-Sea Deposits of the Challenger Expedition.

so largely formed of carbonate of lime that I have taken the latter as a basis for estimates upon the rate of chemical sedimentation, an allowance being made for the presence of silica, alumina and magnesium in the limestones.

Rate of Deposition of Recent Deposits.—Of the rate of deposition in recent deposits Messrs. Murray and Renard state, in their report on the deep-sea deposits, that: "It must be admitted that at the present time we have no definite knowledge as to the absolute rate of accumulation of any deep-sea deposit, although we have some information and some indications as to the relative rate of accumulation of the different types of deposits among themselves. The most rapid accumulation appears to take place in the Terrigenous Deposits, and especially in the Blue Muds, not far removed from the embouchures of large rivers. Here no great time would seem to have elapsed since the deposit was formed, so far at least as the materials collected by the dredge, trawl, and sounding tube are concerned.

"Around some coral reefs the accumulation must be rapid, for, although pelagic species with calcareous shells may be numerous in the surface waters, it is often impossible to detect more than an occasional pelagic shell among the other calcareous debris of the deposits.

"The Pelagic Deposits as a whole, having regard to the nature and condition of their organic and mineralogical constituents, evidently accumulate at a much slower rate than the terrigenous deposits, in which the materials washed down from the land play so large a part. The Pteropod and Globigerina oozes of the tropical regions, being chiefly made up of the calcareous shells of a much larger number of tropical species, must necessarily accumulate at greater rate than the Globigerina oozes in extra-tropical areas or other organic oozes. Diatom ooze, being composed of both calcareous and siliceous organisms, has, again, a more rapid rate of deposition than the Radiolarian ooze, while in a Red Clay there is a minimum rate of growth."[1]

[1] Report on the scientific results of the voyage of H. M. S. Challenger; Deep-Sea Deposits. 1891, pp. 411-412.

Professor James D. Dana estimates that the rate of increase of coral reef limestone formations, where all is most favorable, does not exceed perhaps a sixteenth of an inch in a year, or five feet in a thousand years. Of this he says, "And yet such limestones probably form at a more rapid rate than those made of shells."[1]

Messrs. Murray and Irvine, in their valuable paper on coral reefs and other carbonate of lime formations in modern seas, calculate the total amount of calcium in the whole ocean to be 628,340,000 million tons; also they estimate that 925,866,500 tons of calcium are carried into the ocean from all the rivers of the globe annually. At this rate it would take 680,000 years for the river drainage from the land to carry down an amount of calcium equal to that at present existing in solution in the whole ocean. They say further: "Again, taking the 'Challenger' deposits as a guide, the amount of calcium in these deposits, if they be 22 feet thick, is equal to the total amount of calcium in solution in the whole ocean at the present time. It follows from this that, if the salinity of the ocean has remained the same as at present during the whole of this period, then it has taken 680,000 years for the deposits of the above thickness, or containing calcium in amount equal to that at present in solution in the ocean, to have accumulated on the floor of the ocean."[2] According to this calculation the mean rate of accumulation over existing oceanic areas is $\frac{22}{680000}$, or .000032 feet per annum.

Was the Deposition of Chemical Sediment More Rapid in Paleozoic Time?—It has been claimed that the quantity of lime poured into the ocean in earlier times was greater than during the later epochs of geological history,—this arising from the more rapid disintegration of the Archean, crystalline and volcanic rocks. It is undoubtedly a fact that the ocean was stocked in Archean and Algonkian time with matter in solution that produced salinity, but we have no evidence from chemical precipitation that more

[1] Corals and Coral Islands, 3rd Ed., 1890, pp. 396-397.

[2] Proc. Royal Soc., Edinburgh, Vol. 17, 1890, p. 101.

calcium was poured into it than could be retained in solution. The Laurentian limestones are crystalline, but, as has been shown, this texture is consistent with either chemical or organic origin. The unaltered limestones in the Algonkian rocks of the Colorado Cañon section show traces of life in thin sections, and they may be, to a great extent, of organic origin. There is no evidence in the texture, bedding or composition of these ancient limestones to indicate that they were deposited under conditions of salinity or of supply differing materially from those of the present, and I do not find that we have reason to believe that the deposition of the carbonate of lime was more rapid in the Paleozoic than during the Mesozoic and Cenozoic times, even though the supply from the land may have been greater. Where the conditions were favorable for the deposition of lime, as in the Cretaceous sea of northern Mexico, we find evidence of an immense accumulation of calcareous sediments. Of the amount of calcareous deposits in the seas outside of the continental areas that are not open to our inspection, we know nothing; but judging from the deposition that is going on to-day in the great oceans, the accumulation of calcareous sediment has gone on in the past as steadily and uninterruptedly as at present, subject to varying conditions of temperature, life, depth of water, etc.

Area of Deposition in Paleozoic Time. — We have no proof that the salinity of the sea or the amount of calcium contained in it has varied from age to age since Algonkian time. If it has not, all of the calcium poured into the ocean during 2,000,000 years would have about equaled the amount now contained in the limestones of that area. We have, however, to account for the calcium deposited in the interior Mississippian sea and the seas over other portions of this continent and other continental areas, and on portions of the floor of the ocean that are now accessible for observation. It is also to be considered that the land areas subject to denudation in Paleozoic time were, in all probability, of no larger extent than at the present time.

The area of dry land to-day is estimated to be 55,000,000 square miles, and of oceans 137,200,000 square miles.[1]

Mr. T. Mellard Reade estimates the area of the Paleozoic formations of Europe at 645,600 square miles in the total area of 3,720,500 square miles. His estimate of the Paleozoic area is of that which is exposed at the present time, and does not include that which is concealed beneath other formations. I think it will be a minimum estimate to consider that an equal area is covered by the later formations, which, with that exposed, would give in round numbers 1,290,000 square miles,—or one-third of the land area of Europe. In North America nearly one-half of the total area was covered by the Paleozoic sea; in South America it was considerably less; and we know too little of the Asiatic and African continents to place any estimate upon their Paleozoic areas. I think, however, if we take one-fourth of the present land area as the territory covered by the Paleozoic seas we shall be considerably within the actual amount, even if we add to the surface of the continents the margins of the continental platforms now beneath the sea. Deducting the one-fourth from the total land area, there remain 41,250,000 square miles as the land area undergoing denudation during Paleozoic time. It may be claimed that large areas in the archipelago region of the Pacific and in the Arctic ocean may have been land areas at that time. To meet this, 8,750,000 square miles may be added to the 41,250,000, giving a total of 50,000,000 square miles as the land area of Paleozoic time.

The estimated areas of the various deep sea deposits of to-day, containing a large percentage of the carbonate of lime, are as follows: Globigerina ooze, 49,520,000 square miles, mean percentage of carbonate of lime, 64.53; Pteropod ooze, 400,000 square miles, percentage of carbonate of lime, 79.26; Coral mud and sand, 2,556,000 square miles, mean percentage of carbonate of lime, 86.41. In addition to this, Diatom ooze covers an area of 10,880,000 square miles, with 22.96 percentage of carbonate of lime; and the mean percentage of carbonate of lime in the

[1] Dr. JOHN MURRAY: Scottish Geog. Mag., Vol. 4, 1888, p. 40.

Blue Mud and other terrigenous deposits that cover 16,050,000 square miles is 19.20. If we consider only those deposits containing over 64 per cent. of carbonate of lime, we have 52,500,000 square miles, over which there is at the present time a deposition of the carbonate of lime being made. We have roughly estimated that in Paleozoic time the area of the Paleozoic sea, in which deposits were being accumulated, was over 13,000,000 square miles. It does not appear that there is any good reason to suspect that the area of deposition of the carbonate of lime in the open ocean during Paleozoic time was not fully equal to that of the present time. Adding this area of 52,500,000 to the 13,750,000, we have over 66,000,000 square miles as the probable area in which calcium was being deposited in Paleozoic time.

Conditions favorable for a rapid deposition of the carbonate of lime.—The condition most favorable for the rapid accumulation or deposition of the carbonate of lime through organic or mechanical agency is warm water and a constant supply of water through circulation by currents; this is shown by the immense abundance of life where the margin of the continental plateau is touched by the Gulf Stream. Another favorable condition is the supply of carbonate of lime by river water directly into the ocean in the vicinity where the deposition of lime is going on either through organic or inorganic agencies. This is well illustrated by the conditions produced by the Gulf Stream. The oceanic currents, passing along the northeastern coast of South America, sweep the waters of the Amazon through the Caribbean sea into the Gulf of Mexico, where they meet the vast volume of water coming from the Mississippi. These are poured out through the narrow straits between Florida and Cuba and carried northward over the sloping margin of the continental plateau. Under such favorable conditions the deposit must be much greater than in areas where there is little circulation and the supply of calcium is limited to the average which is contained in sea water. If to the preceding there is added extensive evaporation within a partially enclosed sea, the rate of deposition of matter in solution will be largely increased.

The area over which calcareous depositions was going on during Paleozoic time we have estimated at 66,000,000 square miles, which includes the areas of the seas over the continental platforms and those of the surrounding oceans. As the conditions appear to have been more favorable for the deposition of lime in the Cordilleran aud Appalachian seas, we will assume that it was four times that of the open ocean.[1] With a land area of 50,000,000 square miles (*ante* p. 670) and a rate of chemical denudation of 70 tons per square mile per annum, the total calcium contributed to the ocean per year during Paleozoic time would be 3,500 million tons or 3.78 times as much as that estimated for per annum at the present time, which is 925,866,-500 tons (*ante* p. 668). This would have provided 50.7 tons for deposition per annum per square mile in the 65,000,000 square miles of ocean and seas and 202.8 tons for deposition per annum per square mile in the 400,000 square miles of the Cordilleran and 600,000 square miles of similar seas. On this basis 81,120,000 tons (36.4 mile-feet) were contributed per annum from the ocean water to the deposit in the Cordilleran sea ; adding to this the 42,000,000 tons (18.8 mile-feet) contributed per annum by the denudation of the surrounding area to the Cordilleran sea, we have 128,120,000 tons (55.2 mile-feet) as the amount available for deposit per annum in the Cordilleran sea. At this rate it would have required 16,300,000 years to have deposited the 2,007.244,800 million tons (900 million mile-feet) of *calcium* in the Cordilleran sea ; adding to this the 1,200,000 years estimated for the deposition of the mechanical sediments, we have a total of 17,500,000 years as the duration of Paleozoic time.

In reviewing the preceding estimates we must consider that,

[1] Under the reduction of 50 per cent. for the interbedded and intermingled mechanical sediments and 25 per cent. for other material than calcium deposited from solution, the apparent amount of calcium deposited in the Cordilleran sea was greatly reduced. If this same ratio of reduction is applied to other Paleozoic limestone areas, I doubt if over 1,000,000 square miles will be found to contain as large an average amount of calcium per square mile as the Cordilleran area. On this account 1,000,000 square miles is the area taken for the greater rate of deposition of calcium during Paleozoic time.

throughout, I have increased the various factors above those usually accepted: thus, for mechanical sedimentation, one foot in 200 years is used. If the usually accepted average of one foot in 3,000 years is taken the time period must be increased fifteenfold (21,000,000 years), or the area of denudation from 1,600,000 square miles to 24,000,000—or three times the present area of the North American continent.

In the estimate for the amount of chemical denudation the largest average is taken—70 tons of calcium per square mile per annum—and the assumption made that all calcium derived from the adjoining drainage was deposited within the Cordilleran sea. Again, the total supply provided per annum to ocean waters of Paleozoic time is taken as 3.78 times greater than the amount annually contributed to ocean waters to-day; of this, four times as much is assumed to have been taken out per annum per square mile as was taken by the remaining area in which calcium was being deposited.

The area of the Cordilleran sea is given as 400,000 square miles, but it was probably 600,000, if not much more. It may be claimed that the area tributary to the Cordilleran sea was greater than I have estimated. The evidence, such as it is, is against such a view. As a whole I think the estimate of 17,500,000 years for the duration of Paleozoic time in the Cordilleran area is below the minimum rather than above it.

If the estimated rate of the deposition of coral limestones—five feet in 1,000 years—given by Prof. Jas. D. Dana is correct, the 19,000 feet of Paleozoic limestone in central Nevada would have required 3,800,000 years to have accumulated under the most favorable local conditions surrounding a coral reef. With the exception of large deposits of corals in Devonian rocks no appearance of a coral reef is recorded in the Cordilleran area.

TIME-RATIOS OF GEOLOGIC PERIODS.

The time-ratio adopted by Prof. James D. Dana for the Paleozoic, Mesozoic and Cenozoic periods is: 12, 3, and 1, respectively[1]. Prof. Henry S. Williams applies the term *geochronology*,

[1] Manual of Geology, 1875, p. 586.

giving the standard time-unit used the name *geochrone*. The geochrone used by him in obtaining a standard scale of geochronology is the period represented by the Eocene. His time-scale gives 15 for the Paleozoic; 3 for the Mesozoic; and 1 for the Cenozoic, including the Quaternary and the Recent.[1]

The Rev. Samuel Haughton obtained the following time-ratios from the maximum thickness of strata as they occur in Europe:

SCALE OF GEOLOGICAL TIME.

Period.	From Theory of Cooling Globe.	From Maximum Thickness of Strata.
Azoic	33.0 per cent.	34.3 per cent.
Paleozoic	41.0 "	42.5 "
Neozoic	26.0 "	23.2 "
Total	100.0 per cent.	100.0 per cent.

He draws from this the principle—"*The proper relative measure of geological periods is the maximum thickness of the strata formed during these periods.*"[2]

In considering the time-ratios for the Paleozoic, Mesozoic, and Cenozoic rocks of the North American continent, as given by Dana and Williams, I think that a too small proportion has been given to the Mesozoic and Cenozoic. In the Mesozoic of the western-central area occur the coal deposits of the Laramie series and the great development of limestone (from 10,000 to 20,000 feet) in the Cretaceous of Mexico. The limits of this paper do not permit of a discussion of the available data bearing upon geologic time-ratios; but from a comparison of the Paleozoic, Mesozoic, and Cenozoic strata and the geologic phenomena accompanying their deposition, I would increase the comparative length of the Mesozoic and Cenozoic periods so that the time-ratios would be: Paleozoic, 12; Mesozoic, 5; Cenozoic, including Pleistocene, 2.

DURATION OF POST-ARCHEAN GEOLOGIC TIME.

Taking as a basis 17,500,000 years for Paleozoic time and the time-ratios, 12, 5, and 2 for Paleozoic, Mesozoic, and Ceno-

[1] Journal of Geology, Chicago, Vol. I., 1893, pp. 294-295.

[2] Nature, Vol. 18, 1878, p. 268.

zoic (including Pleistocene) respectively, the Mesozoic is given a time duration of 7,240,000 years, the Cenozoic of 2,900,000 years, and the entire series of fossiliferous sedimentary rocks of 27,650,000 years. To this there is to be added the period in which all of the sediments were deposited between the basal crystalline Archean complex and the base of the Paleozoic. Notwithstanding the immense accumulation of mechanical sediments in this Algonkian time, with their great unconformities and the great differentiation of life at the beginning of Paleozoic time, I am not willing with our present information to assign a greater time period than that of the Paleozoic—or 17,500,000 years. Even this seems excessive. Adding to it the time period of the fossiliferous sedimentary rocks, the result is 45,150,000 years for post-Archean time. Of the duration of Archean or pre-Algonkian time, I have no estimate based on a study of Archean strata to offer. If we assume Haughton's estimate of 33 per cent. for the Azoic period and 67 per cent. for the sedimentary rocks, Archean time would be represented by the period of 22,250,000 years. In estimating for the Archean, Haughton included a large series of strata that are now placed in the Algonkian of the Proterozoic of the United States Geological Survey; and I think that his estimate is more than one-half too large; if so, ten million years would be a fair estimate, or rather conjecture, for Archean time.

Period.	Time Duration.
Cenozoic, including Pleistocene	2,900,000 years
Mesozoic	7,240,000 "
Paleozoic	17,500,000 "
Algonkian	17,500,000 "
Archean	10,000,000(?)"

It is easy to vary these results by assuming different values for area and rate of denudation, the rate of deposition of carbonate of lime, etc.; but there remains, after each attempt I have made that was based on any reliable facts of thickness, extent and character of strata, a result that does not pass below 25,000,000 to 30,000,000 years as a minimum and 60,000,000 to

70,000,000 years as a maximum for post-Archean Geologic time. I have not referred to the rate of development of life, as that is virtually controlled by conditions of environment.

In conclusion, geologic time is of great but not of indefinite duration. I believe that it can be measured by tens of millions, but not by single millions or hundreds of millions of years.

CHARLES D. WALCOTT.

ON THE ORIGIN OF THE PENNSYLVANIA ANTHRACITE.[1]

LONG ago, H. D. Rogers showed that the coal regions of Pennsylvania are divided into rudely longitudinal basins or troughs. In passing over the state northwestwardly, one crosses first the Archean area at the southeast, with its patches of Newark or Triassic; then the Great Valley, extending almost unbroken from the Hudson river to Alabama, and showing only Cambrian and Silurian with occasional patches of Devonian and Lower Carboniferous. Crossing the irregular northerly or northwesterly boundary of the valley, he reaches what, for the purpose of this discussion, may be termed the Anthracite Strip, which extends to the Alleghanies; this contains the Cumberland coal field of West Virginia and Maryland, the Broad Top field of southern Pennsylvania, and, still further northeast, the Southern, Middle and Northern Anthracite fields. The Bituminous coal basins, of which Rogers recognized six, are beyond the Alleghanies; the first, between the Alleghanies and Laurel Hill, is well defined near the Maryland line, but becomes less so northward, though it can be traced without difficulty into New York; the second, with Chestnut Hill as its westerly boundary, is the Ligonier Valley, which like the last can be followed into New York; the third, wider than the second, is less defined at the west, as its boundary on that side is an anticline passing but a little way east from Pittsburgh and producing insignificant topographical effects; the most important portion of the basin, in this connection, is the first sub-basin, known as the Connellsville coke basin, which follows the westerly foot of Chestnut Hill. The remaining bituminous basins, including the rest of

[1] Abstract of a paper read before the Geological Society of America, August, 1893.

Pennsylvania, northwestern West Virginia and eastern Ohio may be regarded as one, their details being unimportant in so far as the present study is concerned.

The trend of the anticlinal and synclinal axes is not N. N. E. and S. S. W. throughout, for one of the great curves of the Appalachian system is within Pennsylvania; the axis of the First Bituminous basin, for example, follows an almost W. S. W. direction until, in Clearfield county, midway in the state, its course is changed to S. S. W.; any topographical map of Pennsylvania illustrates the condition.

Interesting variations in the rate of dip are shown along a line drawn from Pittsburgh, Pa., southeastwardly across the coal area to the Cumberland field in Maryland, the contrast between the terminal conditions being very great. At Pittsburgh, the rate seldom exceeds one degree; in the Connellsville sub-basin it varies from four or six degrees along the lower portion of the trough to somewhat more than ten degrees on the side of Chestnut Hill, the increase in rate thus far being quite regular. No further increase is found in crossing the second and first basins, the dip even on the easterly side of the Alleghanies rarely exceeding twelve degrees. But the extent of disturbance becomes markedly greater at once after the Anthracite Strip has been reached, for there dips of 20, 40, 70 and 80 degrees are seen.

The conditions observed along this line are not representative of those throughout the coal area, for in all the basins, even in those of the Anthracite Strip, the degree of disturbance eventually becomes less along the trend northwardly. The existence of the anthracite fields themselves is due to a remarkable decrease in violence of the disturbance, a dying away northward of anticlines, permitting formation of broad synclines, which in their turn act as do the canoe synclines of the bituminous areas, which, rising, send the lower formations into the air. Southwardly, the condition is markedly different; for though the extent of disturbance, except in the Anthracite Strip, decreases rapidly, the decrease is due to depression of anticlines and not,

as at the north, to the general elevation of the synclines and their passage into the New York plateau.

Analyses of coal samples, taken from the Pittsburgh bed in the several basins, show a progressive decrease in the proportion of volatile, combustible matter toward the east or southeast, a fact which early attracted the attention of H. D. Rogers, and which has possessed much interest for geologists ever since. Analyses made for the Second Pennsylvania Survey prove the same condition in the lower coals. Mr. Winslow's studies of the Arkansas coals show a similar tendency to decrease in the same direction; and Murchison discovered a like condition in the Donetz anthracite field of southern Russia.

H. D. Rogers,[1] in 1842, announced to the Association of American Geologists the law of gradation, as he understood it, which involves "a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it in the driest anthracites to an ample abundance in the richest caking coal." Finding, as he believed, that the volatile matter in the coal augments westwardly, precisely as the flexures diminish, he attributed the variation to the influence of steam and other intensely heated gases escaping through crevices necessarily produced during the permanent bending of the strata. Under such conditions, the coal throughout the eastern basins, the more disturbed, would discharge more or less of the volatile constituents during the violent earthquake action, whereas the more western beds, less disturbed, would be less debituminized.

J. J. Stevenson,[2] in 1877, showed that the variations in volatile exhibited by the Pittsburgh coal bed along the southeast and northwest line bear no relation whatever to increase or decrease of stratigraphical disturbance, and suggested that the variations are due to difference of conditions under which the coal was formed.

[1] ROGERS: Reps. of the 1st, 2d and 3rd meetings of the Association of American Geologists and Naturalists. 1843, pp. 470 et seq.

[2] STEVENSON: 2d Geol. Surv. of Penn., Rep. of Progress on the Fayette and Westmoreland Dist. Pt. I. pp. 61, et seq.

J. P. Lesley,[1] in 1879, offered some interesting suggestions. If the anthracite be metamorphosed bituminous coal, the change might be caused by exposure to comparatively high temperature at a great depth below the surface. As the temperature increases one degree Fahrenheit for each fifty feet, more or less, of descent, the coal under cover of a great thickness of rock could not fail to be deprived of its volatile matter. He compares the composition of coal from the highest available bed in western Pennsylvania with that from the lowest bed in the same region, and finds less volatile in that from the lower bed. As all of the Paleozoic rocks thicken eastwardly, there must have been a much greater pile of Coal Measures in the anthracite region than in the bituminous areas, though erosion has removed the proof. Necessarily then the coals of the anthracite region should show less volatile than do those of the bituminous area, where the pile of rocks was less thick.

Professor Lesley suggests also that if one desire to explain the origin of the anthracite by oxidation in preference to metamorphism, the conditions afford basis for such explanation, since in the anthracite region the rocks are not only broken and shattered by the folding, but they are made up largely of sand and gravel, so that the conditions are such as to favor percolation of water, evaporation, and consequently oxidation; whereas, in the undisturbed bituminous areas, clayey beds are in large proportion and lute down the buried coals so as to prevent percolation and the rest.

There is no possible room for doubt that bituminous coal can be converted into anthracite by heat. The Galisteo, Elk Mountain and other localities within the United States, the Hesse Cassel and New Zealand areas in foreign lands, prove beyond dispute that, under proper conditions, contact with molten rocks suffices for the conversion. But no question of such conversion is at issue here, for in Pennsylvania no dikes occur near enough to the anthracite areas, or large enough even if near enough, to

[1] LESLEY: In McCreath, 2d Geol. Surv. of Penn., 2d Rep. of Progress in the Laboratory, etc. 1879, pp. 153, et seq.

produce by contact the extensive tracts of anthracite still remaining in the state.

Professor Rogers's explanation seems to have been based throughout on a misunderstanding of the conditions. There is no good reason for supposing that the Appalachian Revolution was produced by violent disturbances such as those imagined by Professor Rogers; on the contrary, there appear to be the best of reasons for supposing the final folding to be but an acceleration of the process which had gone on, perhaps not continuously, from a very early period. The slowness of the process even at the close is suggested by the courses of the main waterways. The fundamental error, however, respects the relation of dip and volatile. The dip along the line selected by Professor Rogers, that from Pittsburgh to the Cumberland coal field in Maryland, does indeed show great changes, but as already stated they are not gradual. Let the condition be recalled. At Pittsburgh, the dip is from ½° to 1°; in the Coke basin, 30 miles away, it is from 4°–6° at the lower portion of the trough, to 10°–12° higher up the side of the anticline; in the Salisbury basin, 34 miles further, the dip is the same or less, there being practically no change in the interval from the Coke basin; and no further change is found until one has passed the Alleghanies and entered the Anthracite Strip, where a marvelous change is seen, for the dip is sometimes vertical. Now despite all this, the decrease in volatile, as shown by the Pittsburgh coal bed along this line, is almost regular; thus at Pittsburgh, the average analysis shows of volatile 40.7 per cent. (ash and water being ignored in the calculation); at Connellsville, 33.8, a decrease of 6.9 in 30 miles with an increase of dip from 1° to say 8°; at Salisbury, the volatile is only 23.3, a decrease in 34 miles of 10.5 with no change whatever in rate or type of folding; while in the Cumberland basin, about 15 miles further, the volatile is 18.8, a decrease of only 4.5, despite the complete change in type and remarkable increase in extent of disturbance; and this last field is within the anthracite strip itself, is in proper position, along the trend, to be the continuation of the Northern Anthracite field.

Professor Rogers's error in this matter prevented him from observing that the volatile decreases northwardly along the trend in the several basins even more notably than along the line chosen by him. The hardest anthracite is not in the Southern field, where the folding is most complicated, but in the Eastern Middle. The Southern Anthracite field shows all gradations from bituminous coal at its southern extremity to hard, dry anthracite at its northerly end.

Professor Lesley's suggestion that the Coal Measures attained to much greater thickness in the anthracite region than in the bituminous areas hardly accords with the facts as now known, many of them published since he offered his suggestions. It is altogether certain now that the lower three divisions of the Coal Measures in Pennsylvania, the Pottsville, the Lower Coal Group and the Lower Barren Group, do not show any variations which would justify one in basing a theory upon them; and it is much more than probable that the Upper Coal Group and the Permo-Carboniferous attain their greatest thickness in the north central portion of the Appalachian basin, and that they diminish in thickness westwardly, northwardly and eastwardly from southwestern Pennsylvania, as abundantly appears from the measurements made by I. C. White and by the writer in Pennsylvania, Ohio and West Virginia. In any event, the thickness of the mass in northeastern Pennsylvania was small in comparison with the thickness of the series in Virginia, West Virginia and Kentucky, on the southeastern edge of the Appalachian basin; yet in those states the coal shows no tendency to be anthracite; that of the Imboden coal bed of Virginia and Kentucky, almost at the base of the Lower Coal Group of Pennsylvania, is richly bituminous.

Nor does the theory that anthracite is bituminous coal converted by heat due to mechanical force, commend itself in this connection. The crushed and polished coal of the Broad Top field is bituminous, whereas the uncrushed coal of the Northern field in the same strip is anthracite. The Quinnimont coal, in the gently flexed New River district of West Virginia, has

practically the same amount of volatile as is found in the same coal near Pocahontas, Virginia, close to the great fault of Abbs valley.

But it is unnecessary to look to metamorphism for an explanation of the Pennsylvania anthracite; at best, metamorphism is an unsatisfactory explanation, because it is difficult to find evidence that metamorphosing agencies have been in operation there. One does not think of metamorphism when he finds in the coal of a given bed a variation of five or ten per cent. of volatile within short distances, or even when he finds, as in Sullivan county of Pennsylvania, anthracite in one bench and bituminous in another bench at the same opening.

As was shown long ago by Bischof and others, anthracite can be produced simply by continuation of the process whereby vegetable matter is converted into bituminous coal—by continued formation of carburetted hydrogen until the hydrogen has been removed. Professor Lesley's ingenious suggestion that this can go on more readily in the anthracite region than in the bituminous areas, because of the difference in composition and condition of the rocks, hardly suffices. If only the extremes of the series were to be accounted for, and if all were confined to the anthracite strip, it might be regarded as sufficient; but all gradations from rich caking coal to anthracite occur in the First bituminous basin, where the rocks are comparatively undisturbed and consist largely of argillaceous shale. Moreover, in a single colliery within the Southern Anthracite field, one bench of the Mammoth bed yields a more than semi-bituminous coal, while from another is obtained almost the driest of anthracite. But an equally serious objection is, that the coal must have been converted finally before complete entombment, so that the effect of the pressure would be to remove water and to solidify the coal. The hardening of the coal was complete in the Broad Top field before the Appalachian revolution occurred, for in the final folding the coal, as shown in some mines, was broken into lenticular and polished fragments precisely like those of the Utica shale within the disturbed valley east from the Anthracite Strip. The Lara-

mie coals on the western side of the great plains in New Mexico, Colorado and Wyoming can hardly have undergone any material change since the final burial; otherwise the strange variations in composition would be inexplicable, the difference in condition as to character of rocks and degree of disturbance being insufficient.

Twenty years ago the writer, while connected with the Ohio Survey, reached the conclusion that the marsh, from which sprang the several beds of the Upper Coal group, originated at the east; two years later he was led to assert that the coal beds were formed as fringes along the shore of the Appalachian basin. If this be the true doctrine, there should be found in northeastern Pennsylvania,

First. A vastly greater thickness of coal than in other portions of the basin.

Second. A greater advance in the conversion of vegetable matter into coal, owing to the longer period elapsing prior to entombment.

As to the first condition, there can be no doubt. A comparison of the several divisions of the Coal Measures as they appear in the several basins of the state illustrates it well; but such a comparison would be tedious here, and only the Lower Coal group of the Pennsylvania series is used (that lying between the Pottsville conglomerate below and the Mahoning sandstone above).

In the Anthracite Strip this group shows in the several fields, from south to north, as follows:

Cumberland Field, bituminous,	13′
Broad Top Field, bituminous,	14′–15′
Southern Anthracite, bituminous to anthracite,	18′–60′
Middle and Northern Anthracite, anthracite,	40′–58′

The thicknesses in the Bituminous basins are:

First,	21′–23′
Second,	19′–22′
Fifth,	8′6″–13′4″

The thicknesses, as given for the Anthracite Strip, are those

of coal exclusive of slate and other partings, but those for the Bituminous areas include the slates and other partings, so that the actual amount of coal is less than the figures indicate. It is sufficiently clear that the conditions favoring the accumulation of coal in beds continued longer without interruption in the anthracite region than they did elsewhere within the Appalachian basin; for the contrast is equally marked, when the anthracite region is compared with the Virginias or Kentucky further southwestward. The process of conversion also continued longer without interruption, as the chemical analyses show.[1] Thus, in the Anthracite Strip, one finds:

Cumberland Field (only the Pittsburgh),	4.47– 4.78	Coal, 13′
Broad Top Field, - - -	3.26– 4.64	Coal, 14′
Southern Anthracite Field,		
Southern prong, - -	4.36–12.40	Coal, 18′–30′
Main Field, - - -	11.64–23.27	Coal, 30′–60′
Western Middle Field, -	19.87–24	Coal, 40′–58′
Eastern Middle Field, - -	25.53–30.35	Coal, 52′–53′
Northern Field, - -	19.37–19.92	Coal, 44′–53′

The anthracite analyses are commercial, samples chosen from carload lots. Very much higher ratios are obtained by sampling single benches.

The First and Second Bituminous basins show a similar change along the line of trend, the amount of volatile decreasing northwardly as one approaches the old shore line.[2] Thus, in the First, the Clarion coal bed shows from 2.94 to 4.84 near the Maryland line, but from 7.07 to 10.28 in Sullivan county, where is its last exposure at the north. In the Second basin, the Upper Freeport coal shows 2.26 to 2.85 near the Maryland border, but 3.96 to 4.48 at the last northerly exposure, in Lycoming county. The variations in the Third and other basins are less, as one

[1] The figures here given are the ratios between the Fixed Carbon and the Volatile Combustible, the ash and water being ignored; the more volatile, the smaller the ratio.

[2] Some curious variations, apparently contradictory of the statement here made, occur in the analyses. These will be discussed and their interest shown by the writer in a review of theories respecting the origin of coal beds, which is now in course of preparation.

should expect, for according to the supposition, the conditions at that distance from the old shore line should vary little anywhere.

So one finds,

First. A decided increase in thickness of coal eastward, or better, northeastward toward the anthracite region, and a less marked increase northward in the Bituminous basins.

Second. A decided decrease in volatile in the direction of increased thickness of coal, the decrease being comparatively gradual until near the anthracite fields.

Third. That this decrease is gradual even in the Anthracite Strip from the Cumberland Field to the semi-bituminous coals of the Southern Anthracite field, where the rapid increase in thickness is accompanied by a rapid decrease in the volatile.

When, in 1877, the writer called the attention of his colleagues on the Pennsylvania Survey to the fact that the decrease in volatile is wholly without relation to increase or decrease of disturbance in the strata, he suggested that the variation was due to difference in conditions under which the coal had been formed in the several localities discussed—a sufficiently comprehensive hypothesis, but yielding in this respect to some others of later date. Now, however, there seems to be no good reason for any such suggestion; all that was needed was longer exposure to the process whereby ordinary bituminous coal was formed. In origin, the anthracite coal of Pennsylvania differs in no wise from the bituminous coal of other parts of the Appalachian basin; but because the great marsh, from which sprang the many beds, originated in the northeastern corner of the basin and extended thence again and again on the advancing deltas formed by streams descending from the Appalachian highlands, the time during which the successive portions of the marsh would be exposed would be less and less as the distance from the northeastern and northern border of the basin increased, so that the extent of chemical change would decrease as the distance increased. It is, therefore, to be expected that in the northeastern corner, where the deltas were formed quickly after subsidence was checked, and

beyond which they advanced slowly, as shown by changing type of rocks, the chemical change should have been almost complete, especially in the eastern Middle and the eastern extremity of the Southern field, which occupy that part of the area in which the coal marsh, in almost every instance, appears to have thrust itself first upon the advancing delta.

It is quite possible that when detailed study of the anthracite areas in Arkansas and Russia have been made, the same explanation may be found applicable there also, and that the anthracite will be found near the old shore line, whence the marsh advanced as new land was formed. JOHN J. STEVENSON.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

III. THE GREAT GABBRO MASS OF NORTH-EASTERN MINNESOTA.[1]

A. Introduction.

As has already been stated in an earlier paper,[2] the writer purposes, as time and opportunity permit, to discuss the petrographical and stratigraphical relationships of the basic rocks that constitute such an important element in the geology of the country bordering Lake Superior. In the series of papers, of which this is the first, the petrographical characteristics of the various types of these rocks will be described, and the views held by previous workers with respect to their geological relationships will be outlined. Thus, it is hoped, a foundation will be laid for a new and more thorough investigation of the field relations of these rocks than has heretofore been possible. As the case now stands, several of the geologists who have investigated the eruptive rocks of this region have erred in confusing types of entirely different origins, and have thereby introduced into the literature errors of observation that have rendered a clear understanding of the Lake Superior geology almost impossible.

When practicable the laboratory and field study of rocks should proceed together, each aiding the other in solving the knotty problems that so often arise in their progress. The laboratory study of the eruptives in the region under consideration has been almost entirely neglected, and consequently the field problems arising in connection with them have largely remained unsolved. When the peculiarities of these rocks—their composition and structure—become known, much light will be thrown upon their nature, and it will then be time to again review their field relations, when it is believed that many

[1] This Journal, Vol. I., pp. 433 and 587.

[2] This Journal, Vol. I., p. 435.

of the difficulties now surrounding them will disappear. At present the main results reached by the field-geologists who have busied themselves with the rocks under discussion will be referred to. They must pass unchallenged except in the few cases where the microscopic evidence is directly at variance with them; and when there is no field evidence directly substantiating them. At some time in the near future it is hoped that an opportunity will offer itself for a more detailed study of the rocks in the field. Then it will be proper to criticise the conclusions arrived at by previous workers, and to suggest new views as to the position and relation of the eruptives with respect to the rocks with which they are associated.

B. The Position of the Gabbro.

The great gabbro mass which is the subject of this paper has been placed by Irving in the Keweenawan group, the separation of which from the underlying Huronian slates and quartzites and the overlying Cambrian sandstone, is due principally to the investigations of Brooks, Pumpelly, Irving and Chamberlin. The history of the discussion which has led to the recognition of the great Keweenawan series it will not be necessary to outline, as it is well given in the essays, whose authors have been named.[1]

The only detailed description of the series as a whole has been given us by Irving,[2] who makes it "include only the suc-

[1] It should be stated here that although the individuality of the copper-bearing series of rocks is recognized by nearly all geologists who have worked in the Lake Superior region, several have declined to regard it as a distinct series, equivalent to the Huronian or the Cambrian. These geologists prefer to look upon it as belonging with the latter group as its lower member. Dr. Wadsworth has long held this view, and Prof. N. H. Winchell (8th Ann. Rept. Geol. and Nat. Hist. Survey of Minn., p. 22; 17th ibid., pp. 54-55) in one of his most recent reports sums up the work of the Minnesota Survey in this direction in the statement that the Keweenawan series is closely linked with "the great gabbro flow," to which reference will be made hereafter, and that both are members of the Potsdam. In a later report (20th Ann. Rept. Geol. and Nat. Hist. Survey of Minn., p. 3) the same writer discusses the age of the gabbro and concludes that it is much older than the Potsdam, but he does not assert positively that the Keeweenawan beds overlying it are pre-Cambrian.

[2] The Copper-Bearing Rocks of Lake Superior, R. D. IRVING: Monograph V., U. S. Geol. Survey, Washington, 1883.

cession of interbedded 'traps,' amygdaloids, felsitic porphyries, porphyry-conglomerates, and sandstones, and the conformably overlying thick sandstones, as typically developed in the region of Keweenaw Point and Portage Lake on the south shore of Lake Superior."[1]

Although no distinct line of division between them can be pointed out, the beds of the series naturally fall into an upper division made up wholly of detrital material, principally shales and red sandstones, and a lower division consisting chiefly of a succession of basic flows, layers of conglomerate and sandstone and quite a large proportion of flows of acid eruptive rocks. The thickness of the upper division is estimated at 15,000 feet at its greatest, and that of the lower division at from 22,000 to 24,000 feet.

The recent discovery that the central part of the Keweenawan is underlain unconformably by a great mass of anorthosite, which along the middle portion of the Minnesota coast comes to the surface in many places, suggests to Lawson[2] that the maximum thickness of the lower Keweenawan beds at this place must be much less than Irving's estimate. His own figures are only about one-tenth those of Irving. VanHise[3] in a review of Lawson's article takes exception to the author's small estimate, and prefers to accept Irving's figures, until these are proven inaccurate by careful detailed investigation of the problem in the field.

Since it is only in the lower division that eruptive rocks occur, our attention will be confined entirely to this. It is not possible to determine positively for the entire series the actual succession of the subordinate members belonging in it, for this, in an eruptive series, may vary in different areas, but Irving believes that the following "broad horizons" may be recognized: (1) a succession of heavily bedded coarse-grained olivine and orthoclase gabbros, forming the base of the series; (2) a series of olivine diabases and diabase-porphyrites, occurring at the lower hori-

[1] l. c., p. 24.

[2] Geol. and Nat. Hist. Survey of Minn., Bull. No. 8, p. 21.

[3] Jour. of Geology, Vol. I., p. 312.

zons, together with acid eruptives of all kinds common to the group, as quartz-porphyries, quartzless-porphyries, and fine-grained red granites; (3) olivine-free diabases and other basic rocks with amygdaloidal upper and lower surfaces; and (4) detrital beds, chiefly porphyry conglomerates and sandstones, rare in the lower third of the series, but increasing in thickness and frequency towards the top. These various subordinate divisions have been separated into smaller sub-divisions, and their sequence, where possible, has been carefully detailed, but since a discussion of this classification is not necessary to our present purpose it need not be entered upon.

The lowest of the divisions of rocks belonging in Irving's Keweenawan has been said to consist of a succession of heavily bedded coarse-grained olivine and orthoclase gabbros. The best exhibition of these gabbros is found in north-eastern Minnesota, where the area underlain by them occupies about 2100 miles of the surface of the state, extending from the east line of Range 1, E., to about the middle of Range 15, W. The general shape of the area is crescentic with the concave side turned toward Lake Superior and its convex side facing the north-west. In its widest part the crescent measures about twenty-two miles from south-east to north-west. The chord connecting its two horns is about 125 miles in length. The eastern extremity forms a narrow point about three miles north-west of Greenwood Lake, from which point the area extends westward, widening gradually until it reaches its broadest expanse, and then gradually contracting until it finally abuts against the north shore of St. Louis Bay west of Duluth, where it appears as a band forming the shore line for ten or twelve miles, beginning in the western portion of the city of Duluth and ending four miles east of Fond du Lac.

A second[1] area of basal gabbro is in the Bad River region in Wisconsin. Here the rock forms a narrow belt about forty-eight miles in length and from two to five miles in width, stretching from the Gogogashugun river south-westward to near Numakagon lake, in T. 43 N., R. 6 W., Wis.

[1] Cf. pl. XXII., Copper-Bearing Rocks.

It was not until a few years since that an attempt was made to discover the true relations of these gabbros to the surrounding rocks. In his Copper-Bearing Rocks (p. 266) Prof. Irving places them at the base of the Keweenawan group, at the same time stating that "There is no definite evidence of unconformity between the gabbros and the slates of the Saint Louis River," regarded as Animikie. In a later paper the same writer[1] refers to a coarse-grained, stratiform olivine-gabbro at the base of the Keweenawan.

Though nowhere so stated, the olivine-gabbros had by this time been separated by the author from the overlying "orthoclase gabbros," and had been placed by him at the very base of the Keweenawan group, with the orthoclase-gabbros immediately above them. In his article[2] on the classification of the early Cambrian and pre-Cambrian formations, we have this description of the position and nature of this great mass of rocks, ". . . . We find at the base of the series [Keweenawan] an immense development of stratiform, fresh and often exceedingly coarse olivine-gabbro, the individual layers of which, notwithstanding their complete crystallization, very coarse grain, and lack of amygdaloidal or dense upper surfaces, seem evidently to have formed great flows at the surface of the region as it stood at the time of their extrusion."

No more explicit statements of his views concerning this basal gabbro appear in any of Irving's writings. A reference to the geological map of north-eastern Minnesota accompanying the paper last referred to, will, however, show that at this time (1886) he believed the basal gabbro in Minnesota to rest unconformably upon the Animikie, since the former is represented as cutting transversely belts of St. Louis slates, the Mesabi granite and schists of the Archean, and the eastern area of Animikie slates along the boundary line between Minnesota and Canada, which slates here strike nearly east and west.

Although in his maps the "gabbro flow" is represented as

[1] Am. Jour. Sci., 3d ser., vol. 34, 1887, pp. 204, 249.

[2] Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 419.

belonging with the Keweenawan rocks, the Wisconsin mass was nevertheless recognized by Irving as presenting "the appearance of a certain sort of unconformity with the overlying beds. These gabbros, which lie immediately upon the Huronian slates, form a belt which tapers out rapidly at both ends, and seems to lie right in the course of the diabase belts to the east and west, since these belts, both westward toward Lake Numakagon, and eastward toward the Montreal river, lie directly against the older rocks, without any of the coarse gabbro intervening." . . . "The great extent of coarse gabbro in Minnesota seems to sustain somewhat the same relations to more regularly bedded portions of the series." [1]

The only other descriptions of this great gabbro mass are to be found in the reports of the Minnesota survey. In the report for 1887 Prof. N. H. Winchell[2] details a few of his observations on the "great gabbro flood," and surmises that the "flow" did not escape through a single fissure. The structure of the rock is reported as roughly columnar, with sometimes apparent indications "of the existence of imbricating layers having a gentle dip, as if the fluid rock had swept over the country in successive tides. . . . In texture the gabbro is characteristically coarse. Sometimes some of the constituent minerals are half an inch in diameter. From this they graduate down to an extreme degree of fineness."

From the macroscopic descriptions of other varieties of the rock that follow it is evident that the writer is not dealing exclusively with specimens taken from the great "gabbro flood" at the base of the Keweenawan, for, as the sequel will show, this is composed of a rock which, in its unaltered state, possesses a remarkably uniform texture, and is so well characterized that any departure from it is presumptive evidence that the rock exhibiting the variation belongs not in the "basal flow," but in some one of the numerous smaller beds interstratified with the Animi-

[1] Copper-Bearing Rocks, p. 155.

[2] Geol. and Nat. Hist. Survey of Minnesota, 16th Ann. Rept. for 1887. St. Paul, 1888, pp. 360-362.

kie and the Keweenawan strata at various horizons, or in some one of the many dykes cutting these.

In the report[1] of the following year, upon referring to the position of the gabbro with respect to the other formations, Prof. Winchell says . . . "In general the gabbro lies on the Animikie (Taconic) in Minnesota." At Chub (Akeley) lake, however, it seems to be underlain by a bed of quartzite, regarded as a lower member of the copper-bearing formation of the Potsdam (Keweenawan of Irving and Chamberlin) in the seventeenth report, but looked upon as Animikie and denominated the Pewabic quartzite in the sixteenth report,[2] and described under the field name "muscovado" in earlier reports.

In a more recent discussion[3] as to the age of the gabbro, Prof. Winchell briefly summarizes his previous views on the subject, and concludes that the supposed quartzite underlying the gabbro belongs near the bottom of the Animikie, and since the eruptive rock is so closely associated with the fragmental one, that the former must be of nearly the same age as the latter.[4]

This conclusion is based on the supposition that the rocks immediately underlying the gabbro are fragmental quartzites that have been altered by the eruptive for miles even from its contact with them.[5] But this is probably not always the case. As the writer[6] has shown in another place, some of the so-called quartzites are very basic crystalline aggregates of pyroxene and olivine, and others are granulitic phases of the overlying gabbro. Since they are portions of the gabbro they are of the same age as this, and are not available as stratigraphical data for use in determining the time relations of the great "flow" with respect

[1] 17th Ann. Rept. for 1888. St. Paul, 1891, p. 52.

[2] 16th Ann. Rept., pp. 82-87.

[3] The Iron Ores of Minnesota. Bull. Minn. Geol. Survey, No. 6, 1891, p. 125.

[4] Cf. also: 20th Ann. Report, p. 2.

[5] H. V. WINCHELL: Ib. p. 127.

[6] BAYLEY W. S.: Notes on the Petrography and Geology of the Akeley Lake Region in Northeastern Minnesota. 19th Ann. Rept. Minn. Survey. Minneapolis, 1892, p. 193 et seq.

to the Animikie and the Keweenawan rocks. Some of the rocks, called by Winchell Pewabic quartzite, are probably true Animikie fragmentals, or metamorphosed phases of these, but even in this case there is no proof that the gabbro immediately succeeds them in point of age. The evidence would simply indicate that the eruptive is younger than the Animikie. It would not fix its age more definitely. The observations of Winchell would thus seem to lead to the same conclusion as that reached by Irving in so far as the latter supposed the gabbro to be post-Huronian.

Upon returning again to the problem as to the age of the gabbro Winchell [1] attempts to fix this more definitely by assuming the identity of this rock with the anorthosite, which is shown by Lawson to be older than the bedded Keweenawan. But it is impossible at present to assert with any degree of certainty, that the two rocks are the same (although VanHise holds with Winchell that their equivalency is possible), for the one has not been traced into the other, nor has the upper limit of the gabbro been carefully studied. This great mass may be much older than the lowermost beds of the Keweenawan series, but as yet there has been cited no proof in favor of the view.

So far as the little evidence at hand enables us to judge, the gabbro whose petrographical characteristics are discussed in this article, forms a great mass of enormous extent above the Animikie but below the interbedded flows and fragmentals of the Keweenawan series in Minnesota. There are obscure indications that the mass is a great layer composed of successive flows that followed one another so rapidly as to give no opportunity for the action of erosion processes or for deposition between them. If this be so the lack of more apparent bedding is doubtless due to the great thickness of the individual beds, as is also their coarse grain. There are some things about the mass, however, that suggest another origin for it. "The great coarseness of grain, the perfection of the crystallization, the abrupt termination of the belts, the complete want of structure, and the presence of intersecting areas of crystalline granitoid rocks — all suggest the

[1] Bull. No. 8. Geol. and Nat. Hist. Survey of Minn. p. xviii.

possibility that we have here to do with masses which have solidified at great depths. They certainly cannot, however, be regarded as intrusive in the ordinary sense of the word; so that, unless we regard them as great outflows, we should be forced to look upon them as the now solidified reservoirs from which the ordinary Keweenawan flows have come."[1]

C. Petrographical Description of the Normal Phase of the Gabbro.

Up to the present time there has appeared no general petrographic description of the great gabbro supposed to be at the base of the Keweenawan, although both Irving and Wadsworth have given detailed descriptions of hand specimens taken from it. The former writer,[2] in his monograph on the copper-bearing rocks, refers to the great mass at Duluth as consisting principally of a coarse orthoclase gabbro, but including some orthoclase-free gabbro. The rock is "massive and irregularly jointed, making great ledges facing in different directions, and furnishing bare rounded summits to the hills which it composes.

The prevalent type of the gabbro . . . is of a light gray color, and very coarse-grained, single feldspar crystals sometimes reaching even an inch or two in length. The augitic ingredient is plainly in greatly subordinate quantity, and often on a fresh surface its presence cannot be detected at all. On exposed surfaces, however, the weathering generally brings it out, and then it can be plainly seen to fill the spaces between the feldspars. Titaniferous magnetite is also often perceptible to the naked eye in large particles.

Less commonly the grain is finer and the color darker, the augitic ingredient at the same time becoming more plentiful. In the thin section the predominant feldspar is seen to be a plagioclase belonging near the oligoclase end of the series. There appears also to be a younger feldspar present, which has the character of orthoclase and fills corners between the plagioclase crystals, around whose contours it moulds itself sharply. Streng and

[1] Copper-Bearing Rocks, p. 144.

[2] Copper-Bearing Rocks, Mon. V., U. S. Geol. Survey, p. 266 and 269.

Kloos[1] found 1.61 per cent of potash in the rock, which they very properly regarded as belonging to orthoclase. The spaces between the feldspars are filled with a diallage which is always more or less altered to greenish uralite. The alteration in many sections is carried beyond uralite to chlorite. The magnetite is very large, abundant and titaniferous. Apatites of large size are found in all sections. Biotite is not an uncommon accessory. Olivine is absent from all sections."

It is very evident that the writer is not describing by these words the rock of the great 'flow' as he defined it in his later papers, but that he is dealing exclusively with the orthoclase gabbros, which were afterwards separated from the underlying mass and given a position just above this.[2]

The only specimen of the true basal gabbro examined by Irving[3] came from the Cloquet river, in Sec. 34, T. 53 N., R. 14 W. in Minnesota. This he characterizes as "A very fresh olivine-gabbro. It is light gray in color, very coarse grained, and [is] composed chiefly of very fresh plagioclase (anorthite). Quite fresh diallage fills in the space between the feldspars. A few large fresh olivines occur here and there in the section. Titaniferous magnetite is abundant, and large sized, and biotite occurs in a few small scales."

Dr. Wadsworth[4] made no attempt to describe the general features of this great mass of rock. His descriptions are of hand specimens furnished him for examination by the officers of the Minnesota survey. Among them were several representatives of the "basal flow,"[5] but these were not studied with reference to each other, except in regard to their alterations.

[1] Neues Jahrb. f. Min., etc., 1877, p. 113.

[2] See ante, p. 692.

[3] Copper-Bearing Rocks, p. 272, also p. 46.

[4] Geol. and Nat. Hist. Survey of Minnesota. Bull. No. 2.

[5] The specimens described by Dr. Wadsworth that are thought to belong to the basal gabbro are the following: No. 696, p. 69; 706 and 702, p. 70; 773 and 713, p. 71; 699, 769 and 701, p. 72; 689 and 721, p. 75; 780, p. 85; 707, p. 87; 693, p. 88; 694, 704 and 703, p. 89; 787, p. 90; 715, 692 and 777, p. 91; 691, p. 92; 700, 714 and 698, p. 93; 705, p. 94; 514 and 513, p. 95; 697 and 776, p. 96; and 781, p. 97.

It has already been intimated that the normal rock of the great gabbro is so uniform in its general character that, after studying carefully one of its hand specimens, others might easily be identified among a collection of specimens of the basic rocks of the Lake Superior region, without much danger of error. Its description, therefore, is quite a simple matter. In its macroscopic aspect the normal rock is a medium to coarse-grained, gray, granular aggregate of a very lustrous plagioclase and a black augite. The plagioclase is usually more abundant than the darker mineral; its dimensions are larger, and its contours more frequently approximate to those of crystals. It is of a light gray color and has a glassy lustre on fresh fractures, while on weathered surfaces it is white and opaque. Twinning striations are visible on nearly every grain. The augite on the contrary is jet black. Its cleavage faces are rather small, and its contours never approach those of crystals; they are occasionally triangular or wedge-shaped when they have any definite form, but are usually very irregular in outline. In some of the coarse-grained varieties of the rock there is a rudely lamellar arrangement of both the augite and the feldspar, so that the mass possesses a platy structure. With this exception the gabbro has the typical granitic texture, and is thus easily distinguished from all the other so-called flow gabbros of northeastern Minnesota and the region bordering on Lake Superior in which is more or less perfectly developed the diabasic texture.

The principal varietal differences noted in the rock are due solely to the proportions of feldspar, augite and olivine present in it. When the pyroxene is in moderate quantity the appearance of the specimen is as indicated above. Sometimes the feldspar is largely in excess, and pyroxene has almost entirely disappeared. Now the rock has a lighter gray color, and the bright shining black particles are lacking. Again olivine is the principal component when the tint of the rock becomes dark green. The structure in all cases, however, remains the same. The varieties are merely local phases of the predominant rock for on all sides they grade into one another by insensible transitions. The

density of the varieties depends of course upon their composition; the larger the proportion of feldspar present the lower the specific gravity. Of the three specimens whose densities were determined, one (10440) was found to have a specific gravity of 2.8061, another (8786) of 2.9475, and the third (8589) of 3.0636.

The sections of nearly all specimens taken from the interior of the gabbro area, or from points at some little distance from its northern edge are similar, in that they represent a very fresh rock, whose structure is monotonous and whose composition is quite simple. All contain magnetite, olivine, pyroxene and plagioclase as primary constituents, and many have in addition as secondary components, biotite, chlorite and quartz. The proportions of secondary products present are never sufficiently large to affect the characteristics of the rock as a whole, though they be abundant enough to change materially its appearance in thin section. The usual succession in the formation of the primary minerals is as indicated, and in this respect does the gabbro of the mass under discussion differ most essentially from the other "gabbros" of the same and neighboring regions, for in all of the latter rocks studied the pyroxene is younger than the plagioclase.

The feldspar is the most abundant of the essential components, sometimes constituting, as it does, almost the entire section. It is nearly always in large grains, whose contours are very irregular in shape, and only very rarely resemble those of the lath-shaped grains of diabasic plagioclase. The mineral is quite fresh and is devoid of secondary inclusions, other than a few flakes of kaolin and small flecks of some chloritic substance. The characteristic acicular inclusions of gabbroitic feldspar are sometimes absent from the plagioclase of the Minnesota rock, but more frequently they are present in the usual forms. Small areas of augite and little grains of biotite and magnetite are also enclosed in the feldspar, and dust-like particles are scattered everywhere throughout the grain. The inclusion of augite within the plagioclase would seem to show that the latter mineral is undoubtedly younger than the former; but certain triangular areas of pyroxene between grains of plagioclase would point to

the opposite conclusion. The amount of plagioclase in all portions of the gabbro mass is so great that it must have occupied a long period in its separation. It is probable that the augite began to separate from the magma that yielded the rock some time before the plagioclase, but that after the feldspar began to crystallize the two minerals grew side by side until all the pyroxenic material of the magma had been extracted from it, when the feldspar continued its growth unaccompanied by the formation of pyroxene. Thus some of the plagioclase is older than some of the augite, though the greater part is younger than the great mass of this mineral.

All the plagioclase grains are traversed by broad twinning lamellæ, the maximum extinction on each side of whose composition plane is about 35°. In order to determine accurately the nature of this plagioclase, the three specimens whose densities are given, were powdered and their feldspars separated by the Thoulet solution. Most of the mineral was precipitated when the density of the solution was between 2.674 and 2.728, the limits in the different cases being as follows: in specimen 8786 between 2.700 and 2.728; in 8589 between 2.700 and 2.711, and in 10440 between 2.674 and 2.712. As a small amount of the plagioclase in each specimen was more or less altered, the average of the above figures may be taken as representing the average density of the plagioclase in the gabbro. The method is justified in the fact that the optical properties of the powder in all cases was exactly the same, and that its precipitation was not in steps or stages, but was continuous between the limits mentioned. The mean density of the feldspar separated from the three rocks was thus 2.701, which indicates a very basic labradorite. In the feldspar of a specimen of the gabbro from the Cloquet river Irving[1] reports 52.40 per cent. of SiO_2, while for the most acid member of the bytownite series Tschermak[2] calculates 49.1 per cent. of SiO_2. The largest quantities of the powder in the above three cases fell respectively at 2.700, 2.711 and 2.712.

[1] Copper-Bearing Rocks, p. 439.

[2] Lehrb. d. Mineralogie, 2te Aufl. 1885, p. 439.

There can thus be no doubt that the feldspar throughout the entire mass of the rock is practically of the same character, since the three specimens tested were taken from three widely separated portions of the gabbro area, and each represents a distinct type of the rock. No. 8786 is very rich in olivine, No. 8589 contains much augite and a large quantity of brown biotite, while No. 10440 is very rich in feldspar and quite poor in pyroxene.

An analysis of the feldspar separated from No. 8786, and partial analyses of the plagioclase from the other rocks were made by Dr. W. H. Hillebrand. They are as follows:

	8786	8589	10440a	10440b
SiO_2	51.89	52.18	47.59	46.92
Al_2O_3	29.68	29.20	30.97	31.51
Fe_2O_3	.32	1.11	1.55*	1.29*
FeO	.37			
CaO	12.62	11.18		
MgO	.38			
K_2O	.50			
Na_2O	3.87			
H_2O (100°)	.07			
H_2O (above 100°)	.39			
Total	100.09			
Sp. Gr.	2.700	2.711	2.712	2.674

The figures under 8786 and 8589 correspond very closely with those of a basic labradorite. Those under 10440a and 10440b are abnormal, in that they indicate that the more basic portion of the feldspar in this rock has a lower specific gravity than the more acid one. The alumina in the four cases, however, corresponds quite well with the proportion of this oxide in basic labradorites. In Ab_1An_3, which Tschermak makes the dividing line between labradorite and bytownite, the percentage of alumina present is 32.8 per cent. Since the rock specimens from which these feldspars were separated represent the only phases of the gabbro that have retained the normal gabbro characteristics, it is probable that the feldspars themselves represent the variations within whose limits all of the feldspar in the great mass of the rock may be found. A comparison of this plagioclase with that of the very coarse diabase from the boss-like dike forming Pigeon

* All iron determined as Fe_2O_3.

Point, show it to be a little more acid than the latter, though not enough so as to cause it to be placed in a position in the plagioclase scale far removed from that of the feldspar of the diabase [1]. The corresponding figures for the two plagioclases are:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	Na_2O
Gabbro	51.89	29.68		.69	12.62	3.87
Diabase	53.75	30.39		1.26	10.84	3.76

The augite is generally older than the plagioclase, although the latter mineral seems sometimes to mould the contours of the former one. The pyroxene occurs either in the interstices between the labradorite grains, or as narrow rims around the olivine, forming a mantle that surrounds these and separates them from the feldspar (see Fig. 1).[2] The mineral is very light colored, sometimes being almost colorless, but it is usually tinged

FIG. 1. Section of the olivine-gabbro, exhibiting the tendency of the pyroxene to include olivine grains. Section 1103. × 20.

with pink. It is moreover possessed of a diallagic parting, accentuated by dark decomposition products, the most abundant of which are tiny, irregular black and brown dots. These are scattered everywhere throughout the pyroxene, but are accumulated most thickly in the neighborhood of the cleavage lines. In some of the pyroxene pieces are the peculiar platy inclusions

[1] Bull. U. S. Geol. Survey, No. 109.

[2] Cf. M. E. WADSWORTH, Bull. No. 2, Geol. and Nat. Hist. Survey of Minn., Pl. III. Fig. 1. In this figure the author pictures a pyroxene and olivine bearing the same relation to each other as the diallage and olivine shown in Fig. 1 of this paper.

characteristic of gabbro diallage. These are often arranged in straight lines crossing the parting planes. They are frequently so crowded that the line of inclusions appears as a dark bar crossing the diallage at various inclinations to the cleavage, as in the most notable case (No. 8786), where the direction of the bar cuts the prismatic cleavage at 21° and on the same side of it as the extinction, which is 37° (see Fig. 2). Under polarized light the diallage appears as though polysynthetically twinned. The lamellæ holding the inclusions polarize with a slightly different

FIG. 2. Inclusions in Augite. Section 8786. × ca. 18.

color from that of the inclusion-free lamellæ. Moreover, the material in the immediate vicinity of the several inclusions seems to be more changed from its original condition than portions of the same lamellæ at a greater distance from them. This would indicate that the inclusions have absorbed some of the material of the pyroxene in their growth, and consequently that they are not original inclusions, as are those found by Williams[1] in the Cortlandt peridotites and norites, but are secondary like those discovered by Judd[2] in the peridotites and gabbros of the Western Islands of Scotland.

Under high powers a second cleavage can be detected as a series of fine lines perpendicular to the prismatic cleavage, in sections parallel to the vertical axis. Along these cleavage lines are disposed the inclusions with their long axes so arranged in the direction of the lines as to suggest that the latter were planes of easy solution—that the decomposition of the diallage first took place along them, and then attacked the pyroxene on both sides.

[1] Am. Jour. Sci., 3rd ser., vol. 31, 1886, p. 33; and vol. 33, 1887, p. 141.

[2] Quart. Jour. Geol. Soc., London, vol. 41, 1885, p. 354.

The only other alteration noticed in the diallage is along its edges, where brown and green hornblendes are developed, and in one case where the pyroxene is replaced in part by rosettes of chlorite that polarize in bright blue tints. The very deep pink color of some of the diallage plates may be due to incipient alteration, as along with the change in color there is produced a finely fibrous structure. The writer has searched earnestly for indications of enstatite[1] in the rock under consideration, but has failed to discover any, though strongly pleochroic hypersthene is present in large quantity in certain of its phases to be mentioned later. In one or two specimens of the normal gabbro there is also a little hypersthene, but it is not finely fibrous, and it occurs as very compact plates side by side with equally compact and very fresh plates of diallage.

Much of the pyroxene, as has been said, is in the interstices between the plagioclase and therefore is probably younger than this constituent. It is, however, not in the ophitic areas characteristic of diabasic pyroxene, but is usually in narrow stringers between the feldspar grains, and between these and the olivine. In some sections every grain of olivine is thus separated from plagioclase (Fig. 1), while in other sections, where this is not the case, the diallage is in too small quantity to serve this purpose. Narrow rims of this mineral also exist around magnetite and biotite, and they occur between these two minerals and olivine and a fibrous growth that surrounds them, especially the olivine, in a manner resembling a reaction rim.

Attempts to isolate the diallage for analysis were not successful, as it was found impracticable to free its powder from hypersthene and the brown earthy decomposition products of olivine.

The last mentioned mineral is usually quite fresh, and in large quantity, though in a few specimens it is represented by only an occasional grain in the thin section. Since it was one of the first separations from the magma yielding the rock, it is always present in more or less well defined idiomorphic grains. These are

[1] Cf. M. E. WADSWORTH: Nos. 787 and 692, pp. 90 and 91. Bull. No. 2 Minn. Geol. Survey.

transparent and almost colorless. In thick pieces a yellowish green tinge may be noticed, but in thin slices no recognizable tint may be detected. The inclusions are opaque dendritic particles, spongy magnetite, and secondary products, among which may be mentioned yellowish serpentine, chlorite, and opaque and yellowish-brown earthy substances. These may occasionally entirely replace the original mineral, but more frequently they occur only in the cleavage and other cracks in the fresh olivine, or along its edges.

In most cases the olivine is so fresh that it was thought worth while to have an analysis of it. This has been made by Mr. Hillebrand, who had furnished him a powder consisting of beautifully fresh olivine intermingled with a little diallage, the mixture having been separated from rock No. 8589 by means of methylene iodide. The olivine was isolated by digestion with hydrochloric acid, and the solution obtained was analyzed with this result:

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	CoO	NiO	CaO	MgO	H_2O	Total.
35.58	1.22	.92	tr.	33.91	.35	.20	?	.90	26.86	.31	100.25

The olivine is thus a hyalosiderite with Mg : Fe about 1½ : 1. The small quantities of manganese and cobalt present in it are of interest from the point of view of Sandberger,[1] as affording another indication that olivine is frequently that constituent of a rock which is the source of the material for ore segregations. In the present instance they are of little significance, however, since so far as known the only ores occurring within the large areas covered by the basal gabbro are magnetite and ilmenite. At Copper Lake, in Secs. 9 and 10, T. 64 N., R. 4 W., weathered masses of the gabbro are stained with a green coating of malachite, and the same[2] staining has been noticed at the contact of the Pigeon Point gabbro with a red granophyric rock, where it has resulted from the alteration of chalcopyrite, but in neither case is the copper compound in sufficient quantity to constitute an ore.

[1] Cf. J. F. KEMP: A Brief Review of the Literature of Ore Deposits. School of Mines Quarterly, XI., No. 4, p. 366.

[2] Bull. U. S. Geol. Survey, No. 109.

The relation existing between the olivine and the diallage is the most interesting of the phenomena presented by the rock. It has already been stated that but very few olivine-grains are in direct contact with feldspar. Around nearly all are narrow rims of pyroxene. At first glance these appear to be a sort of reaction rim between the two minerals, but a more careful study of the sections disposes of this assumption, for the surrounding rim frequently broadens out and merges into a well defined diallage plate (Fig. 3). In consequence of the occurrence of the olivine and augite in the manner described sections of the rock exhibit a

FIG. 3. Olivine partly surrounded by narrow rim of pyroxene, which is continuous with large plate of same mineral. 8803. × ca. 18.

kind of concentric structure, with the rounded olivine grains surrounded by a zone of diallage, and imbedded in a mass of plagioclase. Perhaps the most perfect exhibition of this association of the three minerals is shown in the section of rock No. 1103 from the Cloquet River, where the augite is in such large quantity as to completely envelop the olivine (see Fig. 1).

When the pyroxene is in smaller quantity the rim is much narrower, and in many cases is in its turn separated from the plagioclase by a fibrous growth between the last named mineral and itself. This fibrous growth imitates in great perfection many of the reaction rims described by various investigators [1] as exist-

[1] TORNEBOHM: Neues Jahrb. f. Min., etc. 1877, pp. 267 and 384. A. A. JULIEN: Geology of Wisconsin, vol. 3, p. 235, Pl. 22. F. BECKE: Min. u. Petrog. Mitth. 1882,

ing between olivine and plagioclase in many basic rocks. It usually consists of very fine fibres extending perpendicularly from the bounding surfaces of the diallage rim, or when this is lacking, from the peripheries of the olivine grains. In a few instances the fibres form radial groups, centering at points on the exterior of the surrounded mineral. The growth is especially noticeable in the vicinity of the olivine, but it is occasionally also found bordering magnetite grains (Fig. 4) and flakes of biotite. The fact that the fibres are not confined to the borders

FIG. 4. Fibrous intergrowth around magnetite (?) Between the latter mineral and the fibrous rim can be seen a narrow zone of diallage. Section 10439. × 20.

of olivine, but are found as well around magnetite, biotite,[a] and outside of the diallage rims around olivine grains, is presumptive evidence that the growth is not of reactionary origin.

Between crossed nicols portions of the fibrous zone polarize brilliantly, while other portions have the pale blue tint of thin feldspar. Under very high powers the individual fibres are discovered to be discontinuous. They branch, fork and bend in a fantastic manner, and sometimes stop abruptly, while new fibres begin their courses some distance beyond and continue to the edge

iv., pp. 330, 350, 450. G. H. WILLIAMS: Bull. U. S. Geol. Survey, No. 28, p 52. M. SCHUSTER: Neues Jahrb. f. Min. etc., B. B. v. p. 451. TEALL: Mineralogical Magazine, Oct. 1888, p. 116. LACROIX: Bull. Soc. France d. Min., 1889, xii., p. 83.

[a] The biotite is probably secondary so that the occurrence of the fibrous rim around it is of little importance as an aid in determining its nature.

of the rim. It is impossible to determine the character of the fibres in the finest rims, but in those in which the structure is coarser, it is learned that two components are present. One is possessed of a high index of refraction, and strong double refraction, and this appears to be continuous with the diallage of the narrow zones interposed between the fibrous growth and the surrounded olivine. The other component penetrates between the pyroxene fibres, and has club-shaped ends. Occasionally the twinning bars of plagioclase may be detected in it, and hence it is assumed to be a triclinic feldspar. The fibrous rim is thus an intergrowth of plagioclase and augite, both of which minerals are normal constituents of the gabbro. In the fibrous rims they have evidently crystallized contemporaneously, whereas in the main body of the rock the main portion of the diallage preceded the plagioclase in its separation from the magma. There is no necessity for regarding the intergrowths as in any way connected with reactionary processes, while there is abundant reason for believing them to be due solely to the tendency of simultaneously crystallizing minerals to mutually interpenetrate each other. This tendency is well recognized as existing to a marked degree between quartz and orthoclase, whereby granophyre is formed, and to a less extent between various other minerals. Micropegmatitic intergrowths between hornblende and feldspar, for instance, have been described by Lévy,[1] Camerlander[2] and Lacroix,[3] between hornblende and quartz by Kalkowsky,[4] between garnet and feldspar by Becke,[5] and between garnet and quartz by Lacroix (l. c., p. 317,) between diopside and quartz by Lévy,[6] and between various monoclinic pyroxenes and plagioclase by Becke (l. c.), Camerlander (l. c.), Lacroix (l. c., pp. 316 and 318), and Lévy.[7] In the Minnesota rock the diallage in many

[1] Bull. Soc. Min. d. Fr., 1878, p. 41.
[2] Ref. Neues Jahrb. f. Min., etc., 1888, II., p. 52.
[3] Bull. Soc. Franc. d. Min., 1889, XII., p. 319.
[4] Gneissformation, des Enlengebirges, p. 41.
[5] Min. u. Petrog. Mitth. 1878, p. 406.
[6] Bull. des Serv. d. l. Carte geol. d. l. France, No. 9, 1890, p. 7.
[7] Ib. p. 7.

instances sends out tongue-like processes that penetrate far into the plagioclase in which the pyroxene is imbedded (see Fig. 5), so that there can be no doubt that the conditions were favorable to the formation of intergrowths between these two minerals during the period when they were separating from the rock magma. The only essential differences between the fibrous

FIG. 5. Diallage plate and olivine grain in plagioclase. The augite in the bend extends out into the feldspar, giving rise to an intergrowth, very like that of the fibrous rim. 8803. × ca. 20.

intergrowths and that illustrated in this figure are, first, the finer structure of the former, and second, its occurrence around the older components of the rock. Neither of these differences is important, however. Only the second needs a moment's consideration.

The position of the fibrous growth around the olivine and other minerals is due not necessarily to the fondness of the intergrowth for this place, but simply to the fact that the diallage, during the earlier stages of its growth, fastened itself to the solid particles in its vicinity and coated them with an envelope of its material. Continuing its growth it formed the encircling rims of this material that are so characteristic of many specimens of the gabbro, and, when the feldspar began to separate it formed with this the granophyric intergrowth. Since the position of the diallage had already become fixed, the intergrowth naturally was compelled to occupy a place just without this and around the minerals which the diallage had already partially or entirely encircled.[1] Though a fibrous intergrowth of pyroxene and plagioclase with the aspect of a reaction rim surrounding the older minerals of a rock is a rare phenomenon, it is not a unique one, for

[1] For fuller description of the intergrowth, see author's paper in Am. Jour. Sci. XLIII., 1892, p. 515.

Camerlander,[1] in 1887, described a similar intergrowth of these two minerals around the garnets of a contact rock from Prachatitz, in the Bohemian Forest, and mentioned that it strongly resembled the kelyphite rims around garnets in serpentine.[2]

Biotite is present in many sections of the gabbro, though not in all. It not only occurs in the neighborhood of magnetite, where this mineral is in contact with plagioclase, but it is sometimes found imbedded in the feldspar and augite, and at other times it forms a mosaic with decomposed diallage. In basal sections it is reddish brown, and in longitudinal sections is light yellow normal to the cleavage, and dark brownish-green, almost opaque, parallel to this structural feature. In all cases it is probably secondary, for, even when it apparently occurs alone, a very close inspection of its sections will often reveal remnants of magnetite grains imbedded in it. This form of the mineral is evidently a reaction product between the magnetite and the plagioclase by which it is surrounded. The remainder of the mica is probably derived mainly from diallage, since when this mineral is perfectly fresh biotite is absent from the rock, and when the pyroxene has undergone any kind of decomposition, little flakes of biotite are intimately intermingled with its undoubted alteration products. In the broad pieces of diallage in which the dark platy inclusions are so common, little flakes and tiny needles of biotite are frequently discovered lining the cleavage cracks, so that such pieces not uncommonly are crossed by two sets of inclusions cutting each other at some acute angle, one set comprising the gabbroitic kinds already described, and the other set the biotite plates along the cleavage cracks.

Magnetite is widespread throughout the rock, but it is not abundant in most sections. It is in small grains, and in tolerably large areas that are broadly rod-shaped or very irregular in outline. In most cases it occurs between neighboring plagioclase

[1] Jahrb. d. K. K. geol. Reichsanst, 37, 1887, p. 117.

[2] The writer is informed by Dr. J. J. Sederholm that intergrowths similar to those occurring in this Minnesota rock are common in Norwegian gabbros and in one from Ylivilska, in Finland. In his university lectures Professor Brögger calls them "coronites."

grains, but sometimes it is included within them. The larger part of the mineral is undoubtedly primary, while a smaller portion is probably secondary. By its alteration it gives rise to biotite, as mentioned above, through reactions set up between it and the contiguous plagioclase, so that often a grain of the magnetite is entirely surrounded by a true reaction rim composed entirely of biotite. Leucoxene decomposition products were not once observed.

Nowhere in the normal gabbro does the magnetite occur in sufficient amount to constitute an ore, but in certain phases of the rock that have lost entirely the gabbro characteristics, it is known to exist in great quantities. Prof. Winchell[1] describes these ores in detail and gives analyses of them; but most of the titaniferous magnetites of this author's gabbro-titanic-iron group do not occur in the normal rock of his basal mass. They are found either in its peculiar phases to be described later, or in the Animikie and Keweenawan coarse-grained diabases, whose magnetite is always highly titaniferous, and in which there is always an abundance of leucoxene. Only a few qualitative tests have been made on the magnetite separated from the gabbro, but they all agree in showing no trace of titanium. If, upon further investigation, it is found that an absence of titanium from the magnetite of the basal gabbro is characteristic for the rock, an important difference will have been discovered as existing between it and the rocks of the interleaved flows of nearly similar composition in the underlying and overlying series.

The only other original component seen in any sections is apatite. This is in the usual form, as colorless, acicular crystals imbedded in feldspar, and in the various alteration products of the diallage and olivine. It is present only in very small quantity.

Quartz is rare as a secondary substance, mingled with other secondary products in the most altered phases of the rock. In one section (No. 8796) it is filled with tiny, opaque, acicular inclusions.

In order to learn something of the limits through which the rock varies in its chemical composition two specimens were

[1] Bull. No. 6. Minn. Geol. Survey, p. 117 and 125.

analyzed by Dr. H. N. Stokes of the laboratory of the U. S. Geological Survey. No. 8589 contains a large proportion of diallage and olivine, while No. 8786 is more nearly of the average composition of the entire mass.

	8589	8786
SiO_2	45.66	46.45
TiO_2	.92	1.19
P_2O_5	.05	.02
Al_2O_3	16.44	21.30
Cr_2O_3	tr.	
FeO	13.90	9.57
Fe_2O_3	.66	.81
NiO	.16	.04
MnO	tr.	tr.
CaO	7.23	9.83
MgO	11.57	7.90
K_2O	.41	.34
Na_2O	2.13	2.14
H_2O at 105°	.07	.14
H_2O above 105°	.83	1.02
Total,	100.03	100.75

The larger percentages of Al_2O_3 and of CaO in 8786 as compared with 8589, and the smaller percentages of FeO and MgO, substantiate the results of the microscopical study. An increase in the proportions of Al_2O_3 and CaO indicates an increase in labradorite, and a decrease in FeO and MgO, a decrease in the iron-bearing minerals olivine and diallage. The variations are somewhat larger than was to be expected in a rock so uniform in structure and so monotonous in composition as that of this great mass, but they are easily accounted for by the local accumulation of certain of its heavier constituents. So far as known there are no "schlieren" in the normal rock nor any other evidences of a differentiation ("spaltung") of its magma before cooling, so that the variations in mineralogical and chemical composition must be looked upon as due purely to accidental causes. Moreover, the differences are not great enough to effect any material impression upon the rock as a whole. Its characteristics are practically identical throughout an area of several thousands of square miles, and are

quite different from those of the comparatively thin flows between the sedimentary layers of the Keweenawan.

Prof. Winchell, in his bulletin on The Iron Ores of Minnesota, asserts[1] that the "gabbro is found associated with red syenite, quartz-porphyry and various sedimentary rocks in northeastern Minnesota, and, indeed, it passes through unimportant petrographic changes into the well known 'traps' of the cupriferous formation, from which it has not yet been possible to separate it by any important lithologic or stratigraphic distinctions." But since Prof. Winchell has included within his gabbro the rocks of Bellissima Lake, Carlton's Peak and the feldspar masses enclosed in the dark trap of Beaver Bay, it is plain that he does not confine his remark to the rock to which the writer is now limiting his attention, viz., the great coarse gabbro which Irving described as the great basal flow of the Keweenawan. This rock, as has been shown, by a study of specimens taken from very many different localities (see list of specimens studied, p. 714) within the area underlain by it, is so very uniform in its characteristic features that no difficulty is experienced in distinguishing its thin sections from those of any other rock in Minnesota north of Lake Superior.

Summary.—The microscopical study of the gabbro of Irving's "basal flow" at the bottom of the Keweenawan in Minnesota reveals a rock which is uniform in texture and composition throughout its entire extent. It is composed of magnetite, olivine, diallage and labradorite as essential constituents, with a little biotite and occasionally a very small quantity of quartz as secondary components. Its structure, or better texture, is typically granitic in that all of its comprising minerals are hypidiomorphically developed, with the plagioclase younger than the diallage. In this respect the rock is essentially different from the so-called gabbros of the thick flows interbedded with the clastic beds of the Animikie series and the Keweenawan group in the same region, for in the latter, notwithstanding the

[1] L. c., p. 124.

coarseness of their grain, the plagioclase is always older than the diallage, and it always possesses in greater or less perfection the lath-shaped sections characteristic of diabasic feldspar. This being the case, it seems possible that the great gabbro of northeastern Minnesota is not a "flow" or a "series of flows," but is the solidified reservoir [1] in which later flows originated or is a batholitic mass, as Winchell [2] has latterly come to call it.

Further field work on the geological relationships of the mass will probably show either that it is a batholite within the Keweenawan series, well down toward its base, or that, like the anorthosites of Lawson it is an eroded "massive" upon the top of which the later Keweenawan beds have been deposited.

LIST OF SPECIMENS OF NORMAL GABBROS STUDIED AND THEIR LOCATIONS.

1103 (338) 400 N. 200 W. S.E. corner Sec. 34, T. 53 N., R. 13 W., Minn.
6007 (1415) S. side Cross Lake, S. side Sec. 29–64–1 W.
(1416)
(1424)
6011 (1126) S.E¼ Sec. 21–64–3 W.
6013 (1127) N.W. side Copper Lake, Sec. 9–64–4 W.
6127 (1171) N.E¼ S.W¼ Sec. 36–65–3 W.
6128 (1172) S.E¼ S.W¼ Sec. 36–65–3 W.
6130 (3203) S.E¼ S.E¼ Sec. 36–65–3 W.
7025 (2091) S. shore Akeley Lake, Sec. 29–65–4 W.
8589 (4025) S. shore of small lake in S.E¼ S.E¼ Sec. 19–63–9 W.
8786 (3520) Near S.¼ post of Sec. 35–61–12 W.
8788 (3528) N. shore Birch Lake, 200 paces E. of S.¼ post Sec. 24–61–12 W.
8789 (3529) W. side Birch Lake, opposite N.E. arm of lake, Sec. 24–61–12 W.
8792 (3532) N.W¼ S.W¼ Sec. 9–62–10 W.
8793 (4259) N.W¼ S.E¼ Sec. 23–62–10 W.
8794 (3522) On Mishiwishiwi river, near centre Sec. 34–62–9 W.

[1] Cf. *ante*, p. 696.

[2] Bull. No. 8, Geol. and Nat. Hist., Sur. of Minn. Preparatory note, P. xxiv. *et seq.*

8795 (3534) On Mishiwishiwi river, near centre of N½ T. 61–7 W.
8796 (3848) On Mishiwishiwi river, about 2 miles E. of 8795.
8800 (3535) On Mishiwishiwi river, near S. side T. 62–8 W.
8803 (3537) S.E¼ N.E¼ Sec. 7–63–8 W., 250 paces S. of S.E. point of Snowbank Lake.
8869 (4061) S.E¼ Sec. 14–64–7 W.
8896 (3856) N.W¼ Sec. 6–64–5 W.
10000 (3691)
10438 (5068) Half way down W. side Greenwood Lake, Sec. 29–64–2 E.
10439 (5069) Outlet Greenwood Lake, Sec. 33–64–2 E.
10440 (5013) Ca. S.E¼ Sec. 8–59–10 W.
10441 (5014)
10442 (5015)
10443 (5016)
10444 (5070)
10445 (5071)
In order from S. to N. along a stream running from a small lake northward into Birch Lake. First specimen from about N. side of T. 59 R. 10 W.
10537 (5160) S.E¼ S.W¼ Sec. 33–65–5 W.
10538 (4985) S.E¼ S.E¼ Sec. 32–65–5 W.
10539 (4986) S.W¼ S.E¼ Sec. 32–65–5 W. East end of portage between lake Kabamitchikamak and small lake in Sec. 32–65–5 W.
10569 (5181) 1200 paces south N.W. corner Sec. 29–65–4 W.
10570 (4995) 1500 paces S. of N.W. corner Sec. 29–65–4 W.
10638 (5242) North of centre of Sec. 18–64–3 E.

SHOWING APPARENT REACTION RIMS.

6130 (3203), 7025 (2091), 8792 (3532), 8793 (4259), 8795 (3534), 8800 (3535), 8803 (3537), 10000 (3691), 10439 (5069), 10442 (5015), 10444 (5070).

NOTE.—The first number given in each case is the number of the specimen in the collection of the Lake Superior Division of the U. S. Geol. Survey. The numbers in parentheses are those of the corresponding thin sections.

W. S. BAYLEY.

WATERVILLE, ME., July 1, 1893.

Correction.— In the reference (on page 591 of this Journal) to Dr. Wadsworth's work on the Intrusive Basic Rocks of the Marquette region, the date of the publication of the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," is given as 1881. It should be 1880.

It is also stated on the same page that Wadsworth declared these rocks to consist largely of diabase and coarse basalt, both massive and slightly schistose. It was, of

course, not intended by the use of the word "slightly" to intimate that the author did not recognize the true nature of the green-schists of the region. It is well known that in the article referred to that he emphasized particularly the fact that the schists are metamorphosed basic eruptives. He also showed that many of the rocks which still preserve their diabasic and basaltic characters are nevertheless "slightly" schistose, and it is this fact to which it was desired by the writer to call especial attention. This correction is made to prevent misapprehension of the writer's attitude toward the valuable contributions of Dr. Wadsworth to our knowledge of the greenstone-schists of the Lake Superior region. Vide also: Report of the State Board of Geological Surveys for the years 1891 and 1892. Lansing, 1893. Pp. 124–125 and 133–141.

W. S. B.

ON THE GEOLOGICAL STRUCTURE OF THE MOUNT WASHINGTON MASS OF THE TACONIC RANGE.

(With Two Plates.)

Published with the permission of the Director of the United States Geological Survey.

CONTENTS.

Introduction.
Topography.
Previous Work within the Area.
Conditions and Progress of the present Investigation.
Horizons Represented.
Their Lithological Character.
    Canaan Limestone.
    Riga Schist.
    Egremont Limestone.
    Everett Schist.
Explanation of Map, Areal Geology.
Method of constructing Sections.
Structure of the Mountain.
Variable Thickness of the Egremont Limestone.
Metamorphic Character of the Rocks as indicated by Microscopic Studies.
Summary and Conclusion.

THAT portion of the Taconic Range which is known as Mount Washington is both topographically and geologically a unit. It covers an elongated elliptical area, about fifteen miles in length and four and one-half miles in average breadth, lying in the states of Massachusetts, Connecticut and New York. It occupies the entire township of Mt. Washington, and portions of Sheffield and Egremont in Massachusetts; about one-third of Salisbury in Connecticut; and portions of Northeast, Ancram, Copake and Hillsdale in New York.

Topography.—The Mt. Washington mass is a double ridge enclosing a summit plain. Mt. Everett, or the "Dome of the

Taconics" (2624 feet) lying in the eastern ridge, is the highest peak and one of the highest elevations in Massachusetts, while Bear Mountain (2355 feet) is the highest point of land in the state of Connecticut. The main summit plain is situated to the northward of the center of the mass and has an average altitude of about 1700 feet. Corresponding with the elliptical outline of the mountain, this plain is compressed at the north and south, so that its length is about three miles and its breadth two miles. Encircling it is a line of peaks ranging from 1900 to 2600 feet in height. This encircling wall of peaks is buttressed by other peaks both to the northward and southward, the southern side being strengthened by a parallel belt across the mountain, composed of Mts. Bear, Gridley, Frissell and Monument. Southward of this belt of hills the elevated plateau recurs, but without the rampart of peaks which characterize it in the northern and more central area.

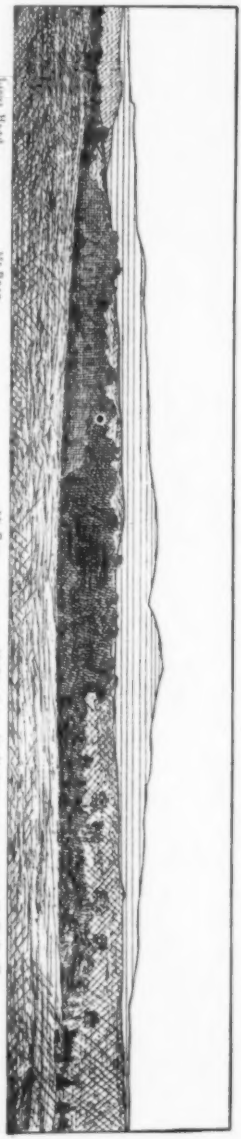


FIG. 1

The Salisbury-Sheffield valley on the east and the Copake Hillsdale valley on the west of the mass, constitute a floor having an average altitude of 700 feet, from which Mt. Washington rises abruptly, the mean slope-angle being about 20°. The southern boundary of the mountain is the nearly east and west valley

through which runs the Central New England and Western Railroad. On the northwest Mt. Washington is merged into the narrow ridge of the Taconics, which extends northward into Vermont. The name Mt. Washington, however, applies properly to all of the range lying south of the South Egremont-Hillsdale turnpike. The regular elliptical contour of the mass is broken on the northeast by two deep embayments, the eastern one containing Fenton Brook, and the western, which is knee-shaped, being occupied by Sky Farm Brook. The regularity of contour is further interrupted by an outjutting spur on the west side, known as Cook's Hill. South of the topographical break which limits the mountain in the neighborhood of Ore Hill, the range of the Taconics pursues a more interrupted course, the hills becoming smaller and spreading out considerably.

Previous Work within the Area.—As the aim of this paper is mainly to deal with the problem of mountain structure, no mention will be made of the part which the area has played in the "Taconic Controversy," except as structural facts may be brought out by it. The boundary between the basement limestone and the schistose rock of the mountain was roughly located by Hitchcock[1] for the northern portion, and by Percival[2] for all but the extreme northern portion of the mountain. The former gives (Plate 55 E of the work cited) a section across Mt. Washington, in which the schist and limestone of the east base of Mt. Everett are shown dipping at a steep angle east. Mather[3] gives two sections across the Taconic Range in the vicinity of Mt. Washington. One of these (loc. cit. Pl. XIV, Fig. 1) is from Hillsdale, N. Y. to Egremont, Mass., and passes a little to the north of Mt. Washington; the other (Pl. XVI, Fig. 3) is from Hudson, N. Y., to the southwest corner of Canaan, Ct. The latter crosses the mountain in a northwest-southeast direction and exhibits a synclinal structure.[4]

[1] Geol. of Mass., EDWARD HITCHCOCK, Amherst and Northampton, 1841, Frontispiece Map.

[2] Rept. on the Geol. of the State of Connecticut, J. H. PERCIVAL, New Haven, 1842, Frontispiece Map.

[3] Natural History of New York, pt. iv. Geology, pt. i. 1845.

[4] In his list of dip and strike observations MATHER includes several from the Mt. Washington area (pp. 612–613).

In 1864 James Hall and Sir William Logan[1] visited Mt. Washington and described it as probably synclinal in structure.

The only investigator, however, who has made a detailed study of the geological structure of the mountain is Professor J. D. Dana, whose papers on the subject have appeared mainly in the American Journal of Science. His first paper dealing with the structure of Mt. Washington[2] appeared in October, 1873. It contains a sketch-map with dip and strike observations. On page 38 he states:

"*Mt. Washington is a synclinal with limestone below and slate above.*"

And on page 39:

"We thus find evidence of a very broad synclinal across the center of Mt. Washington. But just north, in Egremont, the structure is totally different: the ridges S and T[3] are the sources of very steep and comparatively narrow independent synclinals with the axial plane inclined westward. * * * The synclinals S and T become merged in one mass in Mt. Washington; and as the limestone does not appear at the smmmit, the intermediate anticlinal in the mountain was only an anticlinal of slate. In other words, the synclinal of limestone beneath the mass of the mountain was one great trough with breaks and incipient flexures; while to the north these incipient flexures became two defined synclinals, with the intermediate anticlinal — the synclinals being courses in the ridges S and T and the anticlinal that of the limestone outcropping between; and then, farther north, there was formed the Taconic synclinal T alone."

In the same year there appeared in the Proceedings of the American Association a paper entitled "The Slates of the Taconic Mountains of the age of the Hudson River or Cincinnati Group.[4] In this paper Professor Dana states that limestone dips west under slates along the east slope of Mt. Washington for four miles, "that is, the whole eastern front." He describes

[1] Paper read by T. STERRY HUNT before the Natural History Society of Montreal, October 24, 1864. Reviewed in the American Journal of Science, 2d ser., Vol. xl, p. 96 (1865).

[2] On the Quartzite, Limestone and Associated Rocks of the vicinity of Great Barrington, Berkshire county, Mass., J. D. DANA, American Journal of Science, 3d ser., vol. vi., p. 37.

[3] The ridge S is that of Mts. Darby, Sterling and Whitbeck, and the ridge T that of Mts. Prospect and Fray near the New York-Massachusetts state line. (Cf. map pl. i).

[4] J. D. Dana, Proc. A. A. A. S., 22d (Portland) meeting, 1873, pp. 27–29.

the mountain as composed of two close-pressed synclinals in the Mt. Washington plateau with steep easterly inclined axes, and that these synclinals are synclinals of slate riding over a single synclinal of limestone.

In 1877, in a paper entitled, "On the Relations of the Geology of Vermont to that of Berkshire,"[1] he adds, referring to the anticlinals of limestone between the three northern spurs of the mountain:

> "It has not been possible to follow these subordinate anticlinals southward, because the limestone is not continued far in that direction, and the summit of the mountain is under soil and cultivated farms. But yet the fact of flexure at the north end is strong reason for believing that similar flexures, if not the same continued, characterize the whole length from north to south of the mountain-mass, such a slate easily flexing under uplifting lateral pressure. This is further sustained by observations proving that other subordinate anticlinals exist on the western slope of the mountain, in the vicinity of Copake Furnace. Close to the western foot there are two nearly parallel limestone areas, parallel to the axis of the range. The inner (or more eastern) one is about a mile long, and the other about half a mile. They are separated from one another by a thin belt of hydromica slate, and the same slate exists on the other sides. The dip of the beds of limestone and slate is to the eastward 50°, the strike averaging N. 15° E. (true). They are evidently registers of local folds—anticlinal and synclinal, the former bringing up the limestone."

In the paper "On the Hudson River Age of the Taconic Schists,"[2] Professor Dana has put on record new observations showing the synclinal character of the mountain (l. c., p. 376) and printed a map including a part of Mt. Washington (p. 379)[3].

Another paper, "On the Southward Ending of a Great Synclinal in the Taconic Range,"[4] is specially devoted to a consideration of the structure of Mt. Washington, and contains a map of the southern portion of the mountain on a scale of eight-tenths of an inch to the mile. Professor Dana's earlier conclusions as to the synclinal character of the mountain, had been largely drawn from observations made in Massachusetts. The conclusion that the synclinal character of the northern portion of the mountain is continued to the southern extremity, he drew from the fact

[1] Am. Jour. Sci., 3rd ser., vol. xiv., pp. 262–263.

[2] Am. Jour. Sci., 3d ser., vol. xvii., pp. 375–378 (May, 1879).

([3] Cf. also *ibidem*, Supplement to vol. 18, for dip and strike observations).

[4] *Ibidem*, vol. xxviii., p. 268 (Oct., 1884).

that a number of small limestone areas near Lakeville, in which the strata are but gently inclined, are capped by a schist. This schist he believed to be the same as the schist of the southern extremity of the mountain. He says, speaking of these areas (p. 272):

"Since the limestone is the underlying rock, they are all, if not monoclinal, as is hardly possible, small overturned anticlinals, which have had their tops worn off so as to show the limestone beneath." * * * * * *

"The synclinal structure of the mountain is apparent also along portions of the southern edge of the schist. At Ore Hill, one and a half miles west of Lakeville, the schist overlies limestone."

On page 273 he says:

"The ore-pits that have been opened about the base of Mt. Washington, fourteen in number, are situated near the junction of the limestone and schist, and in view of the facts that have been mentioned, this means—*near where the limestone emerges from beneath the schist.*"

Referring to the dying out of the synclinal to the south of the mountain, he says:

"Again the pitch of the beds in the last three miles is southward in some parts, instead of eastward or westward, showing a flattening out of portions of the synclinal and subordinate anticlinals."

"It thus appears that in the dying out of the synclinal, besides a flattening of portions of the general synclinal and the introduction of southward dips, there was also a multiplication of small subordinate flexures."

"Farther there is a multiplication of ridges of schist in the limestone area."

"Several such ridges, some quite small, are situated, as the map shows, southeastward of the mountain near the village of Salisbury; and others occur farther east. They consist of the same mica schist as the mountain,—they have generally an easterly dip, often a high dip; and the facts seem to show that most of them are *synclinal* flexures; that they occupy the troughs of local synclinals in the limestone; * * * . Most of them were, apparently, half-overturned troughs so pushed over westward that the dip of the schist is generally eastward." * * * * * * *

The following is quoted from a paper[1] entitled "Berkshire Geology" (pp. 15–16):

"The Mt. Washington schists lie in a trough very much like that of Greylock, but one relatively shorter in its narrowed part and reversed in position. In the northern half the trough is a very broad shallow one, while to the south the east side is pushed up westward."

[1] Berkshire Geology, by Prof. JAMES D. DANA. A paper read before the Berkshire Historical and Scientific Society of Pittsfield, Mass., February 5, 1885. Pittsfield, 1886.

In Professsor Dana's last series of papers[1] on the Taconic Area, he adds some strike and dip observations and prints a more complete map of the area. In the second of the papers,[2] on pages 439–442, he describes the variations in character of the schist of Mt. Washington as showing a more intense degree of metamorphism in the eastern portions, and in conclusion states (p. 441): "The facts here reviewed relate, it should be remembered, to a single stratum, that overlying the limestone."

The several extracts above given will, I think, sufficiently explain Professor Dana's views regarding the structure of Mt. Washington.

On the geological map of the Taconic area compiled by Mr. C. D. Walcott,[3] the Mt. Washington mass is indicated having the same relations to the rocks of the adjoining areas as is shown on Prof. Dana's map.

Conditions and Progress of the Present Investigation.—The writer made a partial reconnaissance of Mt. Washington in the season of 1889, but the mapping was largely done during the months of July and August, 1891. He was assisted during the season of 1891 by Mr. Louis Kahlenberg, at present instructor in chemistry in the University of Wisconsin. Mr. Kahlenberg has traced the contact of schist and limestone along the west base of the mountain. The work has been in charge of Professor Raphael Pumpelly, then chief of the Archean Division of the U. S. Geological Survey.

The reconnaissance of 1889 was made on the southeastern flank of the mass and furnished only equivocal evidence concerning the relations of the "Stockbridge" limestone of the valley to the schist of the adjacent flank of the mountain. One of the first results of the work of 1891 was the discovery of a calca-

[1] On Taconic Rocks and Stratigraphy, with a Geological map of the Taconic Region, J. D. DANA, Am. Jour. Sci., 1885 and 1887.

[2] *Ibidem*, 3d ser., vol. xxix., June, 1885.

[3] The Taconic System of Emmons, and the Use of the Name Taconic in Geological Nomenclature, by CHAS. D. WALCOTT, Am. Jour. Sci., vol. xxxv., pl. iii. (May, 1888).

reous horizon occupying the central Mt. Washington plateau, and the locating of its boundaries (cf. map). Observations were then made a little to the north of Salisbury village which showed conclusively that the schist of that vicinity is *below* the limestone, the structure of the mountain at that latitude being essentially an anticlinal. On examining next the northern extremity of the mountain, observations were quite as conclusive in proving that the schist of Jug End is *above* the valley limestone, and that the section across the range at this latitude is essentially what Professor Dana has described. This knowledge that we have to do with two horizons of schist, the one lower and the other higher than the limestone of the Egremont valley, was soon followed by the discovery of lithological differences between the different beds, which have furnished the key to the structure. Topographical features soon suggested a course across the mountain through which the limestone might pass and separate the upper schist of the northern portion from the lower schist of the southern portion. Through this path the calcareous horizon of the Egremont valley, considerably modified it is true, has been carefully traced. A large number of observations have been gathered from all parts of the mountain mass. Each of the numerous peaks has been ascended and as many data as practicable have been collected. At this time the southern portion of the mountain had not been carefully studied. Later in studying the area lying to the east and southeast of the mass of Mt. Washington, it was found that the limestone of that section is divisible into two beds separated by a schist, which is lithologically identical with the lower of the two horizons of schist in Mt. Washington. The evidence supporting this and the manner in which the areal relations are illusive in the indications which they afford regarding stratigraphy, will be set forth in a later paper. The lower of the two limestone horizons was found to extend westward and disappear under the schist of the south end of Mt. Washington. The schist overlying it, which so resembled the lower of the Mt. Washington schists, was also traced along the northern border of the limestone into the southern portion of Mt. Washington. The areal

relations in the vicinity of the mountain are set forth on Plate III.

Horizons Represented.—The Mt. Washington series thus consists, not of two members as supposed by Dana, but of four, two of which are calcareous. The calcareous beds alternate with the schists, which have been shown to possess marked lithological differences. The sequence of these beds is as follows: (a) a calcareous horizon which I designate the Canaan Dolomite from its typical development at Canaan; (b) the lower schist bed, which I call the *Riga Schist* from Mt. Riga peak where it is perhaps most typically developed; (c) a calcareous horizon, which I designate the Egremont Limestone from its wide extent in the Egremont valley (this limestone is much modified in all localities above the valley floor); and (d) the upper schist horizon, to which I give the name *Everett Schist* since it assumes its maximum thickness within the area at Mt. Everett. It will be noticed that this sequence corresponds with that which Dale has determined for the Greylock mass in northern Berkshire county.[1] Below are given in parallel columns for comparison the series of Mt. Washington and Greylock:

Mt. Washington Series.	*Greylock Series* (*Dale*).
1. Canaan Dolomite.	1. Stockbridge Limestone.
2. Riga Schist.	2. Berkshire Schist.
3. Egremont Limestone.	3. Bellows Pipe Limestone.
4. Everett Schist.	4. Greylock Schist.

These beds are probably Ordovician though the lower portion of the Canaan Dolomite may, like the Stockbridge Limestone, be Cambrian.[2] No fossils have as yet been found in the vicinity and it is hoped that further search may reveal them. Walcott[3] has

[1] The Greylock Synclinorium, by T. NELSON DALE. Amer. Geologist, July, 1891, pp. 1–7. Also given in detail in a forthcoming monograph of the U. S. Geological Survey, by Professor RAPHAEL PUMPELLY.

[2] On the Lower Cambrian Age of the Stockbridge Limestone, by J. ELIOT WOLFF, Bull. Geol. Soc. Am., vol. ii. 1891. See also DALE, *ibid.*, vol. iii, pp. 514–519.

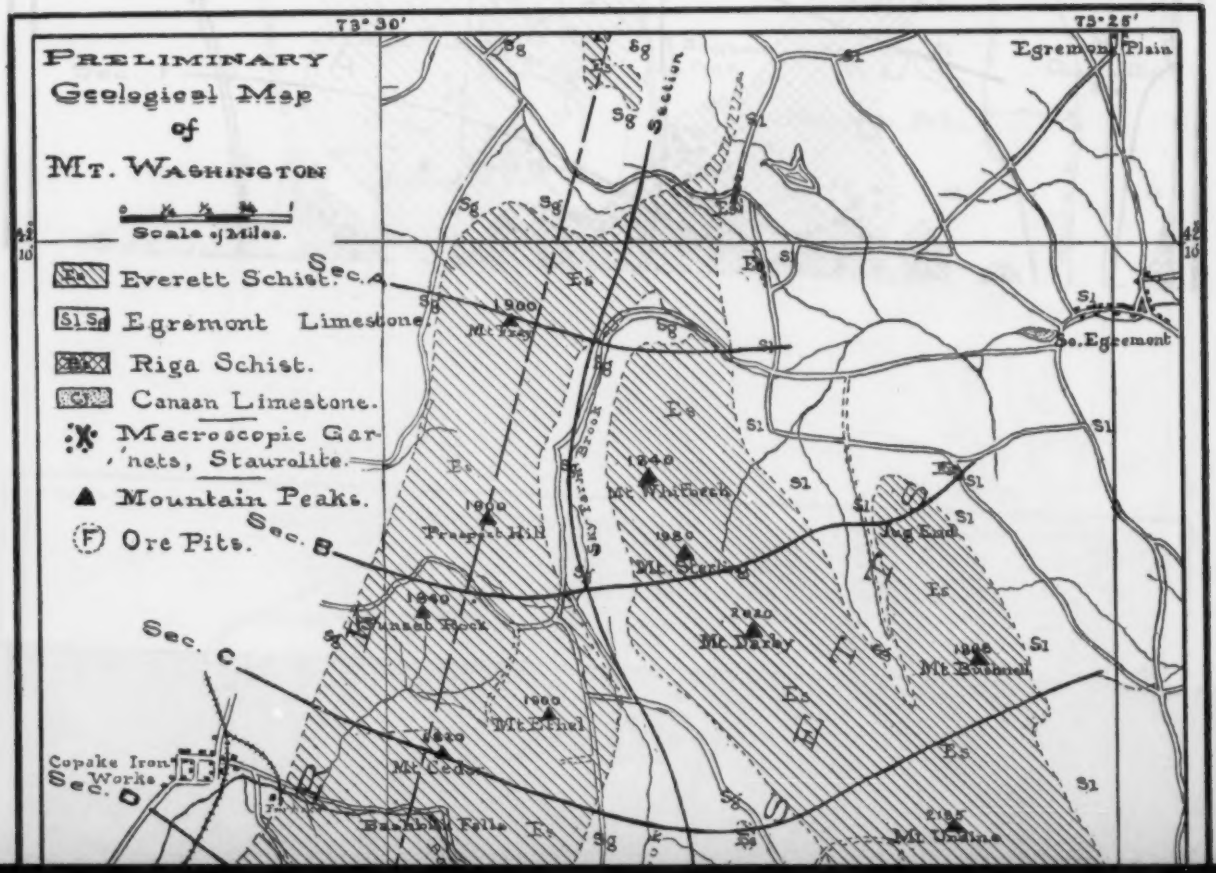
[3] The Taconic System of Emmons, and the use of the Name Taconic in Geological Nomenclature, by CHAS. D. WALCOTT, Am. Jour. Sci., vol. xxxv, pp. 237–242, 399–401, March and May, 1888. (With map).

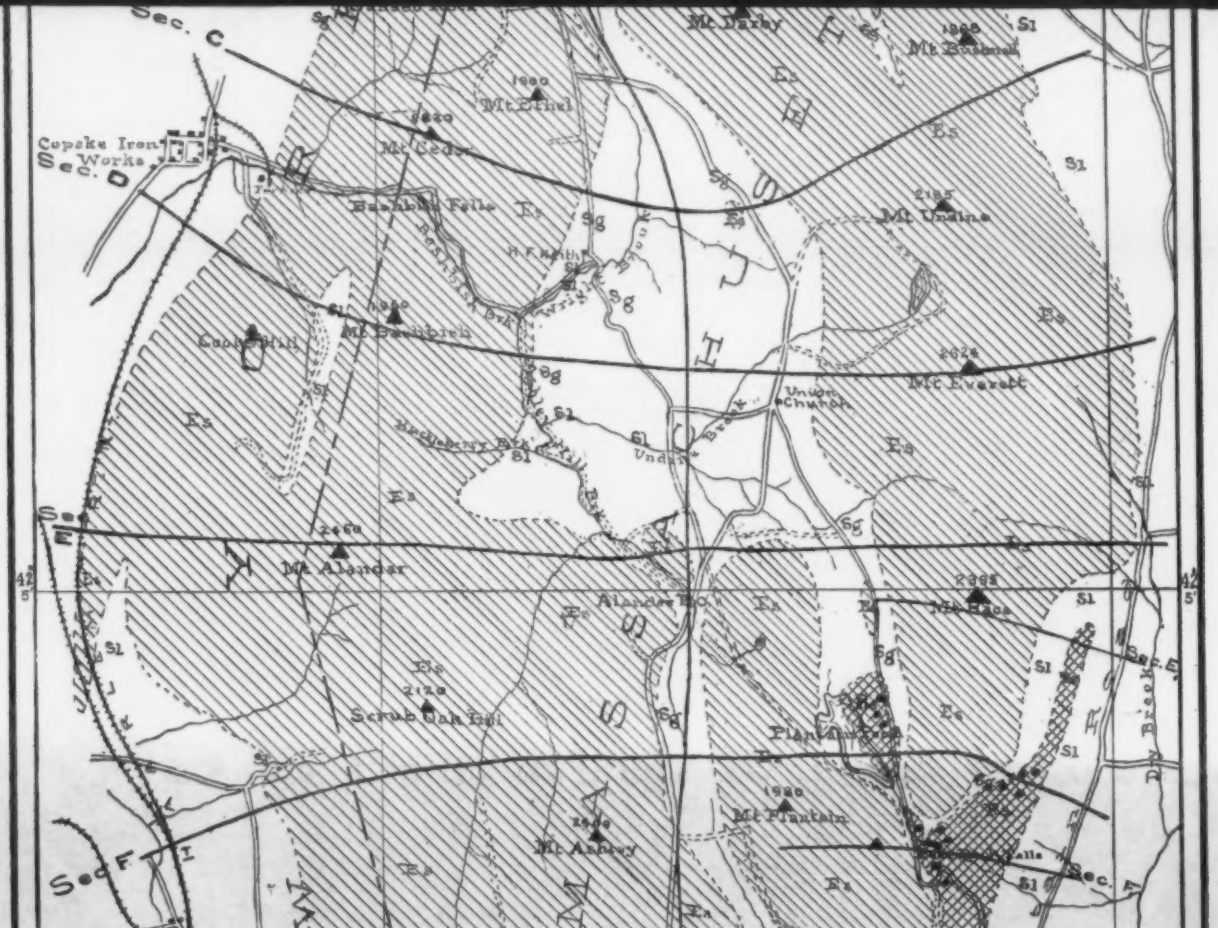
found Ordovician fossils in the limestone belts some distance to the north and Cambrian fossils at Stissing Mountain to the southwest.

Lithological Character of Horizons.—(a) *Canaan Dolomite.* This bed seems to be very rich in magnesia, the rock being in some cases at least a true dolomite. This is shown by a number of analyses of it by Mr. J. S. Adam.[1] This rock appears at the surface only in the extreme southeastern portion of the area here considered, where it presents few features different from those which are common to the Egremont Limestone. Farther to the eastward, however, and particularly in the vicinity of Canaan, it is often characterized by the presence of interesting metamorphic minerals, the well known salite and tremolite of that locality. Phlogopite also has in one or two instances been found. In its upper layers, where it approaches the overlying Riga Schist, the rock may become graphitic, as at Ore Hill. As it appears in the vicinity of the mountain, however, the rock presents no characters which can be relied upon to distinguish it from the higher Egremont Limestone, and the differentiation is based on stratigraphy alone.

(*b*) *Riga Schist.*—This horizon is tolerably uniform in character, the principal differences being in the presence and variable size of the metamorphic mineral individuals. Strictly speaking the rock is a gneiss, owing to the abundance of feldspar, but in order to distinguish it from more feldspathic and more or less granitoid gneisses lying east of the Housatonic River, it is best to refer to it as a schist, which it most resembles in structure. It almost invariably is porphyritic from the presence of lenticular to spherical grains of an acid plagioclase. The base is usually composed of feldspar, quartz, and a colorless mica (in part sericite) and biotite. Considerable graphite often exists in this base as does also ilmenite. Chlorite when present is usually in small amount. Garnets, staurolite, ottrelite, and biotite, as well as plagioclase, are developed at many localities. On the summit of the Lion's Head the rock contains garnets (rhombic dodeca-

[1] See Am. Jour. Sci., vol. xlv. p. 404, foot note.


Preliminary
Geological Map
of
Mt. Washington
Scale of Miles.
Everett Schist.
Egremont Limestone.
Riga Schist.
Canaan Limestone.
Macroscopic Garnets, Staurolite.
Mountain Peaks.
Ore Pits.
73° 30'
73° 25'
Egremont Plain
Sec. A
Sec. B
Sec. C
Sec. D
Section
Mt Frey
Prospect Hill
Mt Whitcomb
Mt. Sterling
Jug End
Bunker Rock
Mt. Darby
Mt Bushnell
Mt Ethel
Mt Cedar
Copake Iron Works
Bashbish Falls
Mt Undine
So. Egremont


Sec. C
Sec. D
Copake Iron Works
Mt Darby
1980
Mt Ettrel
2620
Mt Cedar
Buckbill Falls
Mt Undine
2185
Mt Everett
2624
Union Church
Mt Alander
2460
Alander P.O.
Mt Race
2385
Sec. E
Scrub Oak Hill
2120
Plant Alander
Mt Plantain
1920
Mt Ashley
2469
Sec. F
Sec. G
Sec. H
Sec. I
Sec. J
Sec. K
Sec. L
Sec. M
Sec. N
Sec. O
Sec. P
Sec. Q
Sec. R
Sec. S
Sec. T
Sec. U
Sec. V
Sec. W
Sec. X
Sec. Y
Sec. Z
Sec. AA
Sec. BB
Sec. CC
Sec. DD
Sec. EE
Sec. FF
Sec. GG
Sec. HH
Sec. II
Sec. JJ
Sec. KK
Sec. LL
Sec. MM
Sec. NN
Sec. OO
Sec. PP
Sec. QQ
Sec. RR
Sec. SS
Sec. TT
Sec. UU
Sec. VV
Sec. WW
Sec. XX
Sec. YY
Sec. ZZ
Sec. AAA
Sec. BBB
Sec. CCC
Sec. DDD
Sec. EEE
Sec. FFF
Sec. GGG
Sec. HHH
Sec. III
Sec. JJJ
Sec. KKK
Sec. LLL
Sec. MMM
Sec. NNN
Sec. OOO
Sec. PPP
Sec. QQQ
Sec. RRR
Sec. SSS
Sec. TTT
Sec. UUU
Sec. VVV
Sec. WWW
Sec. XXX
Sec. YYY
Sec. ZZZ
Sec. AAAA
Sec. BBBB
Sec. CCCC
Sec. DDDD
Sec. EEEE
Sec. FFFF
Sec. GGGG
Sec. HHHH
Sec. IIII
Sec. JJJJ
Sec. KKKK
Sec. LLLL
Sec. MMMM
Sec. NNNN
Sec. OOOO
Sec. PPPP
Sec. QQQQ
Sec. RRRR
Sec. SSSS
Sec. TTTT
Sec. UUUU
Sec. VVVV
Sec. WWWW
Sec. XXXX
Sec. YYYY
Sec. ZZZZ

Boston Corners
Mt Frissell
2420
Mt. Monument
2340
Mt. Bess
2355
Mt. Gridley
2200
Sec. G
Sec. H
Sec. I
Sec. J
Chapinville
Chapinville Sta.
Bingham Pond
Mayo Bush
Lake Rigo
Sunset Pond
Tonkers
Moore Brook
Mt Rigo Sta.
Sl
Sg
Ps
Es
Brk.

Sec. I
Sec. J
Mt Rigi Sta.
Chapinville
Chapinville Sta.
Bingham Pond
Lake Rigi
Moore Brook
Sl
Pe
Sg
Rs

Sec. K
State Line St.
T3°30'
73°25'

hedra) over a centimetre in diameter, and staurolites (usually inclined-cross twins) a centimetre or more in length. Tourmaline occurs only in minute crystals, much less widely distributed than any of the other metamorphic minerals except ottrelite. Some of the localities where macroscopic garnets and staurolites were found in the rock have been indicated on the map—small black circles and crosses standing for the two minerals respectively.

(*c*) *Egremont Limestone.*—This horizon as developed in the valley near the base of the mountain, is a white to gray crystalline limestone, which is often quite pure but for small scales of colorless mica and grains of pyrite. Locally it contains thin quartzitic or schistose layers. Generally it passes upward into the Everett Schist of the flanks of the mountain through a graphitic layer of variable thickness, and a similar graphitic rock is also to be found at its lower contact with the Riga Schist. As met with in the summit plains, the limestone appears under two modifications which grade insensibly into one another. They are (1) a very micaceous limestone or calcareous mica schist; and (2) a graphite schist, often, though not always, calcareous. The first mentioned modification is to be found only in the central portions of the northern summit plain, where the larger streams have cut through the thick drift deposits. It is richest in calcite at two localities, one of which is in the bed of Wright Brook about midway between its confluence with Ashley Hill Brook and the north and south road to the east, and the other is in the bed of City Brook. This rock also occurs in the small brook near the house of H. F. Keith, in the bed of Huckleberry Brook, and at several localities on the Ashley Hill road between Huckleberry and Wright Brooks. It always contains a silvery mica, graphite and pyrite.

In the northern summit plain graphitic schist (here generally calcareous) forms a border separating the micaceous limestone from the Everett Schist which surrounds it. According as it occurs nearer the limestone, it is the more calcareous. In the lower course of Wright Brook it contains layers of calcite over a

centimetre in thickness, while on the road encircling the west flank of Mt. Everett it hardly effervesces at all with acid. At localities south of the central plain the rock only rarely exhibits effervescence with acid. The graphite schist differs from the limestone not only in the large proportion of graphite and the correspondingly small amount of calcite which compose it, but its least calcareous varieties contain also much feldspar and quartz. Garnets and tourmaline have each been found in one specimen, the first near the lower, and the second near the upper schist contact.

(*d*) *Everett Schist.*—The rock of this horizon is not in all cases to be easily distinguished from the Riga Schist. Like that rock it is porphyritic from lenticular feldspar grains, but these feldspars are much more abundant and more constant, and the base is generally more chloritic or sericitic. Ottrelite is found sparingly at some localities. The most striking lithological difference from the Riga Schist, however, exists in the *entire absence of macroscopic garnets and staurolites from this horizon*, not an individual of either species having been found within the entire length and breadth of the area of this horizon exposed, though they have been carefully sought at each locality. The beds seem to become more sericitic along the northwestern foot of the mountain. A phase of the rock which is more characteristic of the southeastern portions of the area is very chloritic with magnetite octahedra sometimes as large a pea. Chloritic phases of the rock also appear in the extreme northern areas.

Explanation of Map, Areal Geology.[1]—The eastern and southern portions of the map are based on the Sheffield and Cornwall sheets of the topographical map of Massachusetts and Connecticut by the U. S Geological Survey, and the portion of the map lying in New York State is compiled from older road maps. The manner in which the Egremont Limestone crosses the mountain separating the Everett and Riga Schist horizons, may well be emphasized by special description. On the eastern side the course of the calcareous horizon as it gains the summit plain is

[1] See Plate III.

suggested by topography. The series of sections in Figure 2 will show this in some measure.

Beginning with Mt. Everett, we find that it presents a uniformly steep eastern slope of Everett Schist, the limestone being in contact near the Undermountain Road. Where the slope of Mt. Race begins a little farther south, an abrupt recession occurs in the face of the range, which extends west to the foot of steep cliffs and south to the road north of Sage's Ravine. Into and

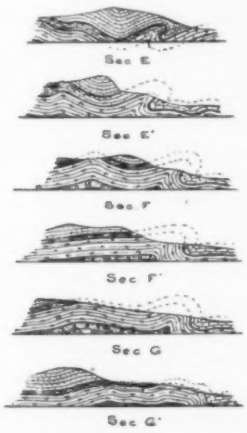


FIG. 2. Series of sections from the east flank of Mt. Washington, showing how the limestone of the valley gains the summit plain.

along this "bench" runs the Egremont Limestone. Proceeding southward from the north end of this "bench," a tongue of schist is met lying within the limestone, about midway between the cliffs and the road, and forming a backbone, the slope immediately west being very gradual while that to the east is tolerably steep. This tongue of schist broadens to the southward, narrowing that belt of limestone which lies to the west of it. As this limestone belt becomes narrowed toward the south, it ascends the mountain, losing as it does so most of its calcite and developing into a black graphitic schist. This reaches the altitude of the summit plain about one-eighth of a mile north of Bear Rock

Falls. From there it is traced with some difficulty along the road to Sage's Ravine, between garnetiferous schists on the east and Everett Schists on the west. The garnets of the eastern schist belt were found to extend northward into the contracted part of the tongue of schist. Immediately north of Sage's Ravine the graphitic rock is distinctly calcareous. West of this point the garnetiferous rock occupies the bed of Sage's Ravine as shown on the map and in sections, while the Everett Schists occur on the road above. To the south of Sage's Ravine and at the altitude of the summit plain, opens a wide bench fully a quarter of a mile in width with the Everett Schists rising abruptly from its western edge in Mt. Bear. To the east of it are thin caps of Everett Schist, then small outcrops of graphitic schists, alternating for a short distance with garnetiferous and staurolitic schists, and finally the latter occurs alone, clearly showing that in the bench and for some distance east of it, the thin bed of graphitic schist lies at the surface. These relations are exhibited in section G′ of Fig. 2. Still farther south this bench is extended into a broad swampy tract on the two sides of which the two schist horizons are shown in outcrops, the garnetiferous rock being on the east and the other schist on the west. This swampy plain outlining the area occupied by the graphitic belt, crosses the north and south Mt. Riga road just north of Mt. Riga (Bald Peak), its northern and southern limits being marked by sharp turns in the road and abrupt rises in the land, as well as by outcrops of the two schist horizons. In the almost continuous areas of exposures in the vicinity of the Mt. Riga Lakes, its course is carved out sharply though the rock is not found in outcrop. Beyond South Pond the belt narrows and begins to be followed with difficulty. The graphitic rock has been found in outcrop in the bed of a stream flowing toward Mt. Riga Station. Farther down this stream is joined by another from the east flank of Mt. Thorpe, containing likewise a belt of graphitic schists (here calcareous) in contact with garnetiferous rock on the west. This belt of graphitic rock is soon cut off to the south, but it is found to join the main valley through a depression of the ridge to the north-

east of Mt. Thorpe, whence it continues northward as a transitional zone between the valley limestone and the Everett Schist. The rock of Mt. Thorpe is filled with garnets, and the area of schist east of the easterly branch of the stream has also abundant garnets, though they have only been found at some distance from the graphitic rock. Between the two forks of this stream, the upper schist rests as in a saddle, its southern termination being a small triangular hill. The southeastern portion of the map, which exhibits areal and structural features of much interest, will receive fuller treatment in another paper, which will deal with the structure of the area to the southeast of Mt. Washington.

Method of Constructing Sections.—The lines of sections have been made as nearly as possible perpendicular to the strike of the strata. The strike has been obtained either by actual measurement with the compass at the locality, or from the directions of the boundaries of horizons. The curvings of the section lines must therefore indicate, either that the crest or trough lines are inclined (pitch) or that the flexures are of variable width. To the southward of section E the average pitch is found to be northward, as shown by the areal relations, and as indicated in the steep southern and gradual northern slopes of the "Lion's Head."[1] To the north of section E the convexity of the section lines towards the south is explained both by southerly pitch and by a greater compression of the flexures in the northern portion. Southerly pitch is suggested by the topography of Mts. Everett and Undine, as well as by the pitching trough and crest lines of coarse corrugations on the slope that rises at the south end of Guilder Hollow (cf. reference to Dale below). These facts when taken in connection with the sections (Plate IV), show the mountain to have a general basin structure.

The determination of the dip is made with great difficulty within the area studied, since the lamination indicative of the plane of bedding is often obscured or even obliterated by subse-

[1] For the detection of pitch by the contour of an elevation I am indebted to Professor Pumpelly for suggestions. He was, I think, the first to discover that these contours betray in an important manner the inclination of the trough and crest lines of folds.

quently induced cleavage structure. In this particular the problems have been essentially those which were encountered in the Greylock area, and similar criteria have been made use of to distinguish the planes of stratification.[1] Hence with the exception of those localities where contacts of the different rocks are exposed, dip observations have been possible at only a few localities where definite plications could be made out.

In the absence of dip observations, the sequence being known, many structural facts have been deduced from the areal relations of the several horizons. Next in importance as a method of determining structure is the interpretation of topographical features. It is by application of all of these methods, whose relative importance is expressed by the order in which they have been mentioned, that the sections have been constructed.

The longitudinal section (Fig. 3) which passes through the mountain in a general north and south direction, nearly at right angles to the cross sections just described, is constructed to show how the northerly pitch of the southern portion of the mountain carries the Canaan Dolomite and the Riga Schist so low that they do not appear again to the northward, for although the pitch in the northern part of the area is southerly, it is not sufficient to entirely counteract the very considerable northerly pitch of the southern portions of the mass.

Structure of the Mountain.—The sections show that the southern portion of the mountain is a geo-anticlinal in the Riga Schist, probably with moderate minor folds tolerably symmetrical. Within the core of this anticlinal is the Canaan Dolomite, which appears from under the schist to the southeast of the

[1] An extensive study of the subject of secondary cleavage as it is met with in the Greylock area, has been made by Mr. T. Nelson Dale, and will appear in full in a monograph by Professor Pumpelly on the Geology of the Green Mountains. A summary of his observations and conclusions is contained in the American Geologist for July, 1891. Mr. Dale has also published a paper entitled, "On Plicated Cleavage-Foliation," in the American Journal of Science for April, 1892. As the writer assisted Mr. Dale during a portion of the field investigation, he became familiar with the structures there exhibited, as he did later also in independent work in the northern stretch of the Taconic Range west of Williamstown.

Sections through MT. WASHINGTON, MASS.

Topography based on U.S.G.S. maps and the author's notes.

Horizontal Scale same as Map.
Sections look North.

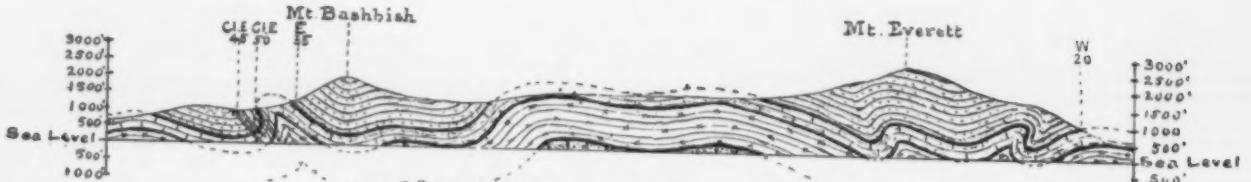
Canaan Limestone.
Riga Schist.
Egremont Limestone
Everett Schist.

Section A

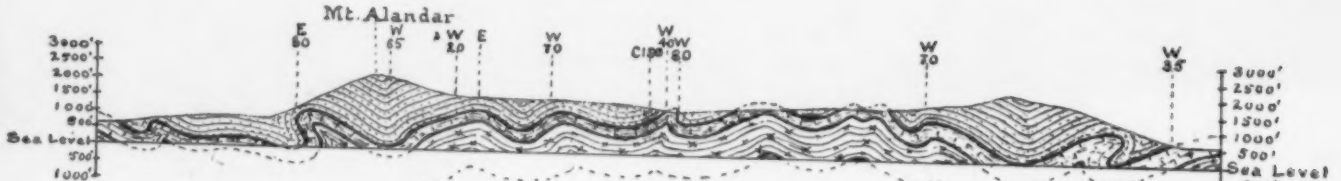
Section B

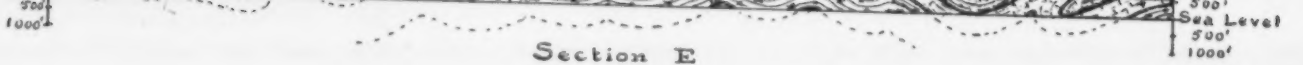
Section C

Section C



Section D





Section E

Section F

Section G

Section F

Section G

Section H

Section I

Section J

Section K

mountain mass. Proceeding northward, one of the minor synclinals in the western limb of the anticlinorium increases in depth and width by a northerly pitch of its trough line, so as to show at the surface, first, the Egremont Limestone, and then more and more of the Everett Schist. The eastern limb of the anticlinal has, in consequence, been narrowed, then compressed and overturned, until east of Mt. Race its axis[1] inclines westward about 35 degrees. The northerly pitch of its crest line carries it continually deeper, until finally it disappears beneath the limestone on the east flank of Mt. Race (cf. Fig. 1). By this process the anticlinorium of the southern portion has been developed in the central portion into a compound fold consisting of two deeply corrugated synclinals (eastern and western schist ridges) and a central corrugated anticilina, which brings the limestone to the surface in the central plain. Proceeding northward still, the flexures sharpen and deepen and become reversed, much as Professor Dana has described. This narrowing of the folds contracts the mountain at its north end, and the succeeding southerly pitching crest and trough lines bring the limestone higher and higher until the overlying schist disappears altogether. To facilitate the comparison of the flexures, Fig. 4 is introduced, the curves being those of the contact of the Egremont Limestone and the Everett Schist as developed in the series of sections. The map, as well as the sections, show that the small schist ridges in the limestone near Salisbury are mainly infolded Riga Schist with the axes of the folds inclined eastward.

FIG. 3. Longitudinal section through Mt. Washington.

Variable Thickness of the Egremont Limestone.— The upper limestone of Mt. Washington forms the

[1] In this paper the term "axis" is used for the axial-plane bisecting a flexure, and never for the crest line or trough line. Cf. MARGERIE ET HEIM, Les dislocations de l' écorce terrestre. Zürich, 1888, p. 53.

western part of the great belt which Professor Dana has mapped in this section of Berkshire county. While it has not been found possible to accurately measure its thickness, it may be safely stated that the thickness never exceeds 600 to 800 feet, and that the beds thin out toward the south end of the mountain. They

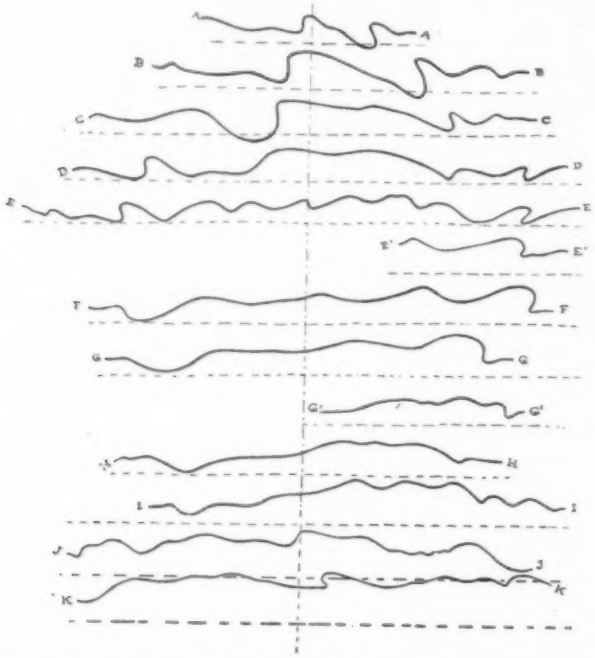


FIG. 4. Series of curves showing the probable form of the flexures in the rocks of Mt. Washington.

also thin out toward the center of the mass from either side. The minimum thickness in the southern portion of the area is probably something less than 100 feet. The general truth of this statement is borne out by an examination of the map and sections (Sage's Ravine, Bear Rock Falls, etc.) As the limestones do not again appear on the southeast flank of the Cornwall-Sharon core of older rocks, it is probable this horizon never

extended much beyond its present limit in a southerly direction. As the bed thins out it becomes more graphitic, indicating also that the conditions attending its formation had here some peculiar local characters.

Metamorphic Character of the Rocks as Indicated by Microscopic Studies.— The microscopic examination of thin sections of rocks from Mt. Washington shows clearly that they are strongly metamorphosed clastics. Evidence has been deduced from the secondary growths of feldspars, garnets, and tourmalines, as well as from the relations of the different metamorphic minerals to one another, to show that the orographic forces to which these minerals owe their development, operated in several more or less distinct periods.[1]

Summary and Conclusions.— What has been set forth in the preceding pages agrees well with Professor Dana's views so far as the northern portion of the area is concerned. In the southern and central portions, however, where the areal and structural relations are more obscure, I have arrived at very different conclusions. This has been due, not to the discovery of errors in Professor Dana's observations, which have been in the main confirmed, but to the collection of a larger number of observations and to the application of some structural principles which were not made use of in his study. A glance at the map will show how perfectly the belt of Egremont Limestone which crosses the southern portion of the mountain, is concealed where it meets the valleys. This belt, the discovery of which furnished a key to the structure, is not at first apparent to the geologist, because at its ends the boundaries of the Riga Schist coincide closely in direction with and form an extension of the boundaries of the Everett Schist.

To summarize briefly the results which have been discussed in the foregoing, the Mt. Washington series consists of four members, which in order of age are as follows: 1) Canaan Dolomite, 2) Riga Schist, 3) Egremont Limestone, and, 4)

[1] Phases in the Metamorphism of the Schists of Southern Berkshire: WM. H. HOBBS. Bull. Geol. Soc. Am., vol. iv., pp. 167–178, pl. 3.

Everett Schist. A somewhat striking lithological distinction, which has been valuable for purposes of identification, is found to separate the two schist horizons, the Everett Schist being entirely free from garnet and staurolite, while the Riga Schist usually (though not always) contains macroscopic crystals of one or both of them. The older rocks are found in the southern portion of the area, a general northerly pitch carrying them successively below the surface as we proceed northward, until at the north end of the mountain we find the upper two members of the series only.

The structure of the mass may be summarized by stating that the beds have been thrown into corrugated folds which seem to have moderate, tolerably symmetrical corrugations at the south end of the mountain, but these corrugations deepen and become frequently overturned as we proceed northward. In the eastern portion of the area the axes of the reversed folds is generally westward. At the extreme south, the structure is a geo-anticlinal, but this develops in the central and northern parts of the area into a geo-synclinal owing to the continued disproportionate deepening and widening of one of its minor western corrugations. The general pitch of the beds is north. A less important southerly pitch which characterizes the northern portion of the area, in combination with the general synclinal structure in cross sections, gives to all the mountain except its extreme southern portion a basin-like character. The rocks are throughout strongly metamorphosed clastics, the orographic disturbances to which they owe their marked crystalline character and porphyritic crystals having operated in several distinct periods. The Egremont Limestone shows a marked diminution in thickness as we proceed southward in the area until it almost disappears. Throughout the mountain plain it is greatly modified, being either a micaceous limestone or calcareous mica schist, or a graphitic schist. The graphitic rock is most developed near the schist contacts and in the southern portion is the only representative of the limestone.

Wm. H. Hobbs.

University of Wisconsin, Madison, Wis.

EDITORIAL.

AT THE recent meeting of the British Association for the Advancement of Science in Nottingham, the section devoted to geology was perhaps the busiest department of the association. Contributions covering nearly all phases of the science crowded the time allotted to the reading of papers. Among them petrology held a prominent position, owing to the eminent character of the president of the section, and to his successful labors in this branch of geology. Mr. Teall based his presidential address upon the data furnished by petrological research, which, to his thinking, lend additional strength to the uniformitarian doctrines of Hutton. By a variety of illustrations he showed the identity of ancient and modern rocks, whether sedimentary, igneous, or metamorphic, and inferred a similarity of physical conditions attending their formation. He emphasized the high degree of differentiation of organic life at the time when the first Cambrian strata were deposited, and maintained that the crystalline schists of earlier age, so far as we have yet become acquainted with them, do not contain the records of the early stages of the planets' history. They can not be considered to represent the primitive crust of the earth. His testimony as to the identity of the volcanic lavas erupted in Paleozoic and Tertiary times in Great Britain, both as regards their structure and composition, allowance being made for subsequent alteration, is significant. It shows that in this region, through a long succession of ages, the groups of rock magmas developed in different periods of volcanic activity have been similar, and that the essential character of the petrographical province did not change.

Sir Archibald Geikie's paper, "On Structures in Eruptive Bosses which Resemble those of Ancient Gneisses," was a valuable

contribution to the study of gneissic structure, since it showed the possibility of a part, at least, of the banding in these rocks being due to a primary banding of igneous masses through some process of segregation or through differentiation of the magma into layers. A parallel banding of igneous rocks in the neighborhood of a plane of contact has been known, but its magnitude is generally inconsiderable. The structure in the gabbro on the Isle of Skye, however, which was described by Geikie, is on a large scale, and without apparent relation to a plane of contact. No attempt was made to suggest a cause for such a mode of segregation, since the study of the locality where it is best developed is not yet completed.

Prof. Brögger's paper, "On the Genetic Relations of the Basic Eruptive Rocks of Gran, Christiania Region," presented an array of facts with regard to the differentiation of rock magmas. By means of chemical analyses and field observations he showed that basic magmas of like composition in neighboring localities had separated into pairs of magmas, which were quite unlike one another chemically; producing dissimilar pairs of rocks. This proves that a given magma may differentiate in more than one manner, according to circumstances. The entire paper is to appear in the Quarterly Journal of the Geological Society.

Mr. Harker discussed the question of magmatic concentration, or differentiation, with reference to its probable cause, and pointed out what seemed to him obstacles to the application of Soret's principle. He suggested that a more probable explanation would be found in Berthelot's principle, or that of maximum dissipativity. The applicability of Soret's principle to the differentiation of magmas is also assailed by Prof. Bäckström in an article to appear in the next number of this JOURNAL, and the principle of liquation advocated. While it is quite probable that all of the phenomena of segregation and differentiation may not be accounted for by one law of diffusion dependent on osmotic pressure, and while this law finds its most perfect realization in the most dilute solutions, and while certain separations of rock magma may take place near the point of saturation, still it can

not be denied that rock magmas at times are known to attain extreme liquidity. Moreover, there must undoubtedly be a number of different physical causes at work conjointly, each of which may preponderate under favorable conditions, so that it is quite probable that no single process will be found adequate to explain all the phenomena in question.

It is interesting to observe that, while the majority of petrologists are engaged in studying the evidences of differentiation of molten rock magmas, the theory of magmatic synthesis proposed by Bunsen is not being wholly neglected. From the nature of a portion of the evidence it is possible to frame diametrically opposite hypotheses, but when all of the conditions are taken into account it would seem that but one of the hypotheses can have a general or far-reaching application. Prof. Sollas's paper, "On the Origin of Intermediate Varieties of Igneous Rocks by Intrusion and Admixture, as Observed at Barnavave, Carlingford," demonstrated how intimately the material of an acid molten magma may penetrate the interstices of a highly fractured rock, in this case basic; the delicate veins thinning to almost microscopic dimensions. Instances of this kind are well known. The assumption, however, that this process has taken place to a very considerable extent, and has produced bodies of rock of intermediate composition, seems to ignore the probable physical conditions under which rock magmas are irrupted, and also the geological probabilities of such things happening. Thus there may be no defect in the logic of the assumption as an abstract idea, but there may be little or no probability of its ever taking place to a considerable extent in nature.

Other petrological papers were presented by Prof. Sollas, Mr. Watts, Dr. Johnston-Lavis, and an interesting account of the volcanic phenomena of Japan was given by Prof. Milne, and illustrated by lantern slides. It cannot be out of place, for one who has been fortunate enough to have been a guest of the Association, to express a high appreciation of the honor, as well as of the generous social hospitality which has become a distinguishing characteristic of these meetings. J. P. I.

Reviews.

Correlation Papers. The Newark System. By Israel Cook Russell. Bulletin 85, U. S. Geological Survey. Washington, 1892.

This Bulletin adds another number to the list of invaluable correlation papers, prepared especially for the Geological Survey, but of the greatest service to all professional geologists and advanced students alike. Prof. Russell's paper is of exceptional completeness from the bibliographical side; its index is a marvel of minute reference; every author's name is followed by a complete list of his writings, the more important ones being analyzed; every locality noticed in any paper is indexed separately, with reference to the place of its mention; occurrences of sandstone, shale, conglomerate and trap are catalogued under these headings. Immediate reference may thus be made to any desired item concerning the Newark system, excepting the fossils, which, for some reason, are not indexed under their names, but only through the authors who have described them.

The chief headings of the text are: Nomenclature, area, lithology and stratigraphy, conditions of deposition, life records, associated igneous rocks, deformation, former extent, correlation and summary. A good number of maps serve to guide the reader to the easy understanding of the several areas into which the formation is divided. I can only comment on a few of these subjects.

Professor Russell has done good service in the fourth headings in showing the incompleteness of the evidence on which glacial action has been argued as an agency in the deposition of the formation. Near the margin of several of the Newark areas, heavy conglomerates, containing boulders up to four or five feet in diameter, are known at various localities; and although none of these deposits are unstratified, they have frequently been appealed to as evidence of glacial action. But none of the boulders are scratched or notably angular; all of them are, as far as known, deposited near the shore of their time; all of them are systematically interbedded with ordinary aqueous deposits. Cer-

tainly they are not unaltered glacial deposits; and to assume that they are derived from such is to imply that no agency but glaciers is competent to move boulders of several feet in diameter. Russell refers to the occurrence of large angular rock masses on the alluvial fans of the arid regions at a distance of two or three miles from their source, to show that the movement of large boulders may take place under subaërial conditions; he cites the absence of ice-borne boulders among the finer strata of the Newark deposits; and he argues a relatively warm, not a cold climate, from the prevailingly red color of the formation and from the character of the fossils. Emerson has detected large boulders in certain basal beds of the sandstones in Northern Massachusetts, demonstrably close to their source, and not in the least indicative of glacial transportation. Indeed, to conclude that glacial action occurred at sea level during the period of Newark deposition simply from the coarse nature of certain marginal conglomerates, is to adopt an open alternative instead of a closed demonstration as a guide to belief.

Another line of evidence may be introduced against Fountaine's argument that the Newark conglomerates of Virginia were derived from glaciers which descended from the Appalachian mountains of that time. Local glaciers could originate in that latitude only on lofty mountains, from which they might descend to sea level, much as those of New Zealand do now. But the evidence gathered from the outline of the under border of the Newark areas does not at all favor the idea that they closely adjoined lofty mountains. If such had been the form of the surface whose submergence allowed the accumulation of the Newark sediments, their under border must have been extremely irregular; the Newark waters must have rounded many a bold promontory and penetrated many a deep bay. The basal sediments accumulated along so sinuous a water margin should now show some indication of these promontories and bays. They should be distributed much in the way that the Permian breccias of Wales lie around their once buried and now resurrected mountains, and thus show their origin on an extremely irregular coast. But as far as the basal beds of the Newark system have been studied out, they do not indicate that the surface on which they lie possessed any great relief at the time of their deposition. Whatever deformation it had previously suffered, whatever mountainous heights this deformation produced, the action of erosion had in pre-Newark time carried away enough material to some unknown goal

to leave a surface of only moderate inequality; by no means of such inequality as would gather snow fields on its higher levels, and shed long glaciers down its valleys into the Piedmont seas.

The prevailing red color of the Newark strata is also adduced by Russell as indicative of a relatively warm climate, as contrasted to a glacial climate. To this might be added that the slow subaërial decay, from which red soils and sediments seem to be derived, is inconsistent with the conditions of decay on lofty mountains, from which the detritus is shed rapidly, leaving a relatively large surface of bare rocks; while it is accordant with the idea of a well denuded region, from which further denudation carries material slowly.

In examining the structural relations of the igneous rocks, it is noticeable that little success has as yet attended the efforts of observers southwest of the Delaware to distinguish between the intrusive and extrusive origin of their trap sheets. It would seem from this that the scouring of the decayed surface of the Newark belts by Pleistocene glacial action has been an advantage to the geologist of to-day in New Jersey, Connecticut and Massachusetts; but an advantage that is frequently offset by the sheets of drift which obscure or conceal so many of the weaker strata in the Connecticut valley. I believe that Connecticut alone has yielded a greater number of localities where the contact of the sandstones on the trap sheets can be actually seen, and from which good hand specimens can be secured, than all the areas beyond the Hudson. It may be noted that the map of the New York-Virginia Newark area, compiled by Russell from such data as he could gather together, does not give a correct impression of the crescentic trap ridges of eastern Pennsylvania. I have only examined a small part of that district, but from what was seen and from the topographic maps of the Perkiomen drainage area, surveyed by the Philadelphia water commissioners for a proposed new water supply, I think that an accurate geological map of the district will disclose a more systematic arrangement of forms than now appears.[1]

The deformation of the Newark areas has been a subject for much discussion already, and it will doubtless furnish as much more in the future. Before it can be successfully deciphered, the stratigraphic succession of the system must be made out; and that has not been generally done, as may be seen from Russell's chapter on lithology and

[1] Since writing the above, I have seen the new geological map of Pennsylvania, on which the curved trap sheets are clearly shown.

stratigraphy; in which the various kinds of rocks are enumerated, but in which their succession and thickness is not stated. The difficulty of the problem lies in the monotony of the strata, and in the doubt in many cases as the origin of the trap sheets. Whatever success has yet been gained in solving this problem, it has come chiefly through the aid given by the old lava flows, and only secondarily through ordinary stratigraphic methods. In Pennsylvania and further south, no complete stratigraphic correlations have yet been established; mainly, as has has been stated above, because the trap sheets there are not yet well deciphered. In New Jersey the discrimination between intrusive and extrusive sheets has been well accomplished, but doubt is felt as to the location of fault lines by which they are dislocated, this doubt resulting from the uncertainty as to the reappearance of identical sandstone strata or trap flows. It is only in the Connecticut valley that the variety of trap sheets and associated sedimentary beds is such as to make the demonstration of faults complete. Here, over a considerable share of the area, the stratigraphic succession is made out with much certainty; and the lines of dislocation are determined with sufficient precision. At the same time certain fossiliferous beds, rare in the formation as a whole, and therefore of all the more value in defining horizons, have been traced for thirty or more miles inland from Long Island Sound; and their dislocations agreeably confirm the conclusions previously reached as to the faulting of the trap sheets.

Like so many other features of this peculiar system of rocks, its style of deformation is exceptional. It is nowhere folded in the ordinary manner; where curvature of bedding appears, it is of such character as to give crescentic outlines to the beveled edges of the strata now visible. The formation is, as a rule, tilted over to a rather regular monoclinal attitude; but while the earlier conceptions of its structure implied that the monocline was practically uninterrupted, the later studies show it to be complicated by numerous faults, traversing the mass in various directions, and as a rule systematically arranged, although the control of the system is obscure. One thing is clear: the faults penetrate the crystalline foundation on which the Newark beds lie; they are not dislocations within the Newark beds alone; indeed, it almost seems fair to say that the dislocating forces were indifferent to the cover of Newark beds, and that their action was chiefly expended on a much deeper mass of rocks

The original extent of the Newark areas has been much discussed,

and Mr. Russell, some years ago, espoused the idea that their present surface was a comparatively small part of their original basins. This matter is essentially indeterminate at present; but the valid evidence of great post-Newark erosion disposes me to accept almost any measure of former extension of the system that may be required by reasonable argument. At first, the mind halts before the supposition that vast masses have been uplifted and worn away in the ages since the date of the Newark deposition, but the evidence of vast denudation in that interval is now so complete that it no longer seems warrantable to withhold belief in the "broad terrane hypothesis," either from its extravagant erosion of rock masses, or from an apparent insufficiency of time for such extravagance.

On the other hand, while it seems likely that there was some connection between the several separate Newark areas, because their fauna and flora are so similar, it does not seem necessary to conclude that all the space between the Connecticut and the New Jersey areas was once overspread by Newark strata. It may have been. There was time enough during the Newark deposition to furnish material for such a cover; and there has been time enough since then to wear it away; but still there is no direct evidence that it existed. The original boundaries of the formation are very vaguely defined.

Noticing that a greater definiteness of results has been gained in the Connecticut valley than in the other Newark areas, it is evident that the physical conditions of origin of the trap sheets in the southern areas deserve the closest scrutiny. If they prove to be intrusive sheets, they are of little structural value. But if they are proved to be extrusive, they may then be treated as conformable members of the stratified series, and thus a key to the general attitude of the system is gained. After this step, the detection of sequences of strata, including extrusive trap sheets with the aqueous sediments, is of next importance, as by this means faults may be located, and thus some advance made in the general reconstruction of the formation.

But even where best studied out, it is likely that the cross sections by which underground structure is represented are hardly more than parodies on the facts; so insufficient are the opportunities for the discovery of deep internal structures. A close knowledge of the system seems beyond reasonable expectation.

W. M. Davis.

Harvard College, November, 1893.

Text-book of Comparative Geology. By E. KAYSER, Ph.D. Translated and edited by PHILIP LAKE. Pp. xii, 426. Swan, Sonnenschein & Co., London. (Macmillan).

The translation of Dr. Kayser's book is a welcome addition to the literature of geology in English. Its title is fairly definitive. It is an attempt to bring together, or to set in their proper relations, the results of geological investigation conducted in the various parts of the world. The volume is too brief to allow this to be carried out in great detail. The abbreviation has been effected in part by the omission, or by no more than the merest mention, of results reached in extra-European countries. This is particularly true with that part of the volume which deals with the post-Paleozoic formations. While at first thought this might seem to detract from the value of the volume for American students, we think on the whole it is an advantage instead, if omissions were necessary. Data concerning American geology are more easily accessible to American students than data concerning European geology, which this volume measurably supplies. The volume will find its chief use in America as a convenient reference book of European geology, and as such it should be widely distributed. Its abundance of tables, showing the relations of the subdivisions of the various systems in different countries, so far as they are made out, are especially convenient for general reference.

At several points in the volume there is a noticeable tendency to make unqualified statements where qualified statements would seem to us better. A case in point is the unqualified denial of the organic character of the Eozoon. It is true in most cases, where positive conclusions are asserted, that they represent the best conclusions of the present day, but in some cases they seem to us to represent probable or qualified or tentative conclusions, not demonstrated or absolute or final ones.

All pre-Cambrian rocks are represented as Archean, though the length of Archean time is stated to be so great that the beginning of the Cambrian "may be considered as comparatively a recent event." In spite of this recognition of the importance of the Archean, but fourteen pages are devoted to its consideration. Although different systems are not recognized in the pre-Cambrian rocks, the diversity of origin of different parts of the group is distinctly recognized. The author is inclined to attach less weight to the existence of limestone and graphite in the Archean rocks, as indications of life, than would

most geologists. He thinks that the strongest evidence for the existence of life in pre-Cambrian time is the high organization of the Cambrian fauna. While geologists will be ready to assent to the strength of this last argument, they will hardly be ready to regard it as the only strong reason for belief in pre-Cambrian life. To the very considerable number of fossil forms already found in pre-Cambrian rocks no reference is made.

The important question of the origin of the Archean is rather briefly dismissed. The discussion touching this question is much less full and much less satisfactory than that of Prof. Van Hise, recently published.[1] Indeed, had Prof. Van Hise's discussion been published before Dr. Kayser's treatise, the latter author might have found a way out of some of the difficulties which seem to lie in his mind concerning the origin of the Archean.

An excellent feature of the book is the prefacing of the discussion of each system by a short account of the origin and history of its differentiation from underlying and overlying systems. Each system is discussed under the general heads of — 1) Distribution and development; 2) Paleontology. Under the first head, it could have been wished that the structural relations of the systems had been more uniformly and sharply brought out. Such clear statements as that concerning the North American Devonian system, that it rests "conformably and without break on the Silurian, and is covered conformably by the Carboniferous" (page 111), are not always to be found. Where knowledge does not permit such positive statements, definite statements representing the degree of present knowledge would have been welcome. So, too, the relations of faunal and stratigraphical breaks are not always so clearly set forth as could have been desired in a text-book.

In the discussion of the Permian system, Dr. Kayser brings out the fact of wide-spread conglomerate formations (India, Victoria, Brazil, South Africa) in tropical latitudes and the southern hemisphere, which sometimes contain polished and striated stones very like those of glacial formations of later date. In Africa the Dwyka conglomerate rests on rock, the upper surface of which is smoothed and striated like rock beneath the modern glacial drift. Dr. Kayser indicates that the belief that these Permian conglomerate beds are of glacial origin has gradually gained ground. The flora succeeding the conglomer-

[1] Bulletin of the U. S. Geol. Survey, No. 86.

ate in Africa, South Asia and Australia is characterized by Mesozoic types. This change is believed by many to have been brought about by the cold climate which was the determining cause of the conglomerate beds. Blanford and Waagen go further and connect the decline of the marine Paleozoic types with the cold climate of the end of the Paleozoic.

In the discussion of the Mesozoic and Neozoic there is scarcely any reference to American geology. In connection with the discussion of Pleistocene geology, two glacial epochs are recognized. The author inclines to the eolian hypothesis for the origin of loess.

Both the physical and paleontological phases of the subjects discussed in the volume are illustrated by numerous figures, the former rather less fully than the latter. A series of maps, showing the distribution and relations of the systems described, would have enhanced the value of the volume which is still great without them.

ROLLIN D. SALISBURY.

Iowa Geological Survey. Vol. I. First Annual Report, 1892. SAMUEL CALVIN, State Geologist, Des Moines, 1893. 8vo, 472 pp., 10 plates and 26 figures.

IN addition to brief administrative reports, the first report of Iowa's third survey contains papers by S. Calvin, C. R. Keyes, Assistant State Geologist, S. W. Beyer, H. F. Bain and G. L. Houser.

The introductory paper by Mr. Keyes, on the Geological Formations of Iowa, is a summary of present knowledge of the various formations occurring within the limits of the state. The writer has availed himself of the various studies made of these rocks in recent years, and the result is shown in an improved classification over that of preceding surveys. While all the formations have come under careful study, the most notable progress is shown to have been made in the classification of the Devonian, the Carboniferous and the Cretaceous.

Investigations in northwestern Iowa have brought to light the presence of undoubted eruptive rocks at no great depth below the surface. In Mr. Beyer's paper are given the details relating to the discovery of typical quartz-prophyry, interbedded with sandstone and gravel, in a deep well at Hull, Iowa. The discovery by Culver and Hobbs of eruptive rock within the Sioux quartzite in southeastern

Dakota is referred to, and, following Hall, White, and Irving, the conclusion is drawn that the Sioux quartzite is the oldest formation in the state. Some familiar names have disappeared from the geological section, and their places are assumed by newer but more appropriate terms, as, for example, Oneota for Lower Magnesian, St. Croix for Potsdam, while Hamilton is represented by four names applied to as many subdivisions. The term Augusta is given to the terranes including the Warsaw, Keokuk and Burlington, in place of William's term Osage which is discarded as inapplicable. The Warsaw beds of Hall are here included with the Keokuk, and the term Warsaw dropped. An error occurs in the definition of the St. Louis limestone on page 72, where it is asserted that the brecciated limestone constitutes the base of the beds in Iowa. This is the case only along the extreme margin of the beds. Seaward from the old shore line, as shown along the Des Moines in Van Buren county, the basal member consists of a brown, magnesian limestone in fairly regular, more or less undulating beds. The texture is sometimes nodular and sandy. In thickness the formation varies from five to fifteen feet or more.

The structure of the coal measures is treated in considerable detail, and emphasis is given to conclusions based largely upon Mr. Keyes' investigations in Iowa. These rocks are included in two stages, the lower or Des Moines, and the upper or Missouri formation, White's middle division being discarded. These are not considered two distinct formations in the sense that the lower was deposited prior to the laying down of the upper—the view commonly entertained—but the two were formed contemporaneously, the former as a marginal or shore formation, and the latter as its deep or open sea correlative. The view here advanced seems to be a modification of that held by Winslow. The conditions of deposition were evidently those of a slowly sinking shore, and the marginal deposits practically underlie the open sea formation though not necessarily much older ; hence the terms lower and upper are retained, though emphasis is given to their general contemporaneity. The summary of Professor Calvin's researches on the Devonian and Cretaceous rocks shows a marked advance in the knowledge of these formations.

The classification of Iowa rocks, given by the different surveys, is here presented for comparison :

HALL'S REPORT, 1858.

- Quaternary. { Alluvium. / Drift.
- [illegible] Cretaceous. { Presence in Iowa asserted, but rocks not described. / Given on Owen's authority.
- Permian ?—Gypsum beds.
- Carboniferous. { Coal Measures. / Carboniferous limestone. { Kaskaskia (not present). / Ferruginous sandstone (not present). / St. Louis limestone. / Warsaw. / Keokuk. / Burlington.
- Devonian. { Chemung group. / Hamilton group. / Upper Helderberg limestone.
- Upper Silurian. { Le Claire limestone. / Niagara limestone.
- Lower Silurian. { Hudson River group. / Galena limestone. / Trenton limestone. / Black River and Birdseye limestone. / St. Peter's sandstone. / Calciferous sandstone. / Potsdam sandstone.
- Huronian—Sioux Quartzite—1866.

WHITE'S REPORT, 1870.

- Post Tertiary. { Alluvium. / Bluff. / Drift. { Altered.
- Lower Cretaceous. { Inoceramus beds. / Woodbury sandstone and shale. / Nishnabotna sandstone.
- Carboniferous. { Coal Measures. { Upper. / Middle. / Lower. / Sub-Carboniferous. { Chester (not present). / St. Louis. / Keokuk. / Burlington. / Kinderhook.
- Devonian—Hamilton limestone and shale.
- Upper Silurian—Niagara limestone.
- Lower Silurian. { Maquoketa. / Galena. / Trenton. / St. Peters. / Lower Magnesian. / Potsdam.
- Huronian?—Sioux quartzite.

CALVIN & KEYES REPORT, 1892.

- Quaternary. { Alluvium. / Loess. / Drift. { Upper till. / Lower till.
- Upper Cretaceous. { Niobrara. { Inoceramus and possibly gypsum beds, and Nishnabotna sandstone. / Fort Benton. } { Woodbury shale, and possibly the Nishnabotna sandstone / Dakota. } {
- Carbonoiferus. { Upper Carboniferous or Pennsylvania Series. { Missouri Stage. / Des Moines Stage. / Lower Carboniferous or Mississippian. { Kaskaskia (or Chester) (not present). / St. Louis. / Augusta { Keokuk. / Burlington. / Kinderhook. { Chouteau lm. / Hannibal sh. / Louisiana lm.
- Devonian. { Lime Creek shale. / Montpelier sandstone. / Cedar Valley limestone. / Independence shale.
- Upper Silurian. { Le Claire limestone. / Niagara limestone.
- Lower Silurian. { Maquoketa. / Galena. / Trenton. / St. Peters. / Oneota.
- Upper Cambrian—St. Croix.
- Algonkian—Sioux quartzite.

Other papers by Mr. Keyes are: "Annotated Catalogue of Minerals," and "Bibliography of Iowa Geology."

Professor Calvin's paper is devoted to the Cretaceous deposits of Plymouth and Woodbury counties. In the region studied these beds are found to be sharply divisible lithologically into two divisions, a lower consisting of soft sandstones, with bands of hard ferruginous concretionary nodules, and variegated, often parti-colored clays, the latter greatly predominating and resting upon these a white or yellowish chalk, somewhat indurated in places into a soft fissile limestone. The first is White's Woodbury sandstones and shales, and the second is his Inoceramus beds. Following Meek and Hayden, Professor Calvin makes a threefold division of the beds, by drawing a somewhat arbitrary line about forty feet below the base of the Inoceramus beds. The lowest division contains impressions of leaves and a meagre brackish water fauna. This he correlates with the Dakota group. The second or middle division of dark colored calcareous shales, containing marine mollusks, associated with the vertebræ and teeth of bony fishes, and the skeletons of marine saurians, is the Fort Benton group of Meek and Hayden. The upper or Inoceramus beds represent the Niobrara of the same authors. During this epoch the Cretaceous sea had its farthest eastward extension, probably reaching as far as the Mississippi river in northeastern Iowa.

Mr. Beyer's paper is entitled Ancient Lava Flows in the Strata of Northwestern Iowa, and relates to the discovery in a well at Hull, Sioux county, of typical quartz porphyry at a depth of 755 feet. Microscopical study shows it to have a pronounced flow structure, while the quartz crystals show the effects of magmatic corrosion, and, in some cases, fracturing with discordant orientation of the fragments, from which it is inferred that the magma was semi-viscous and under great pressure when the flow took place. In the drilling, the eruptive rock was found to alternate with sandy strata, showing evidence of metamorphism down to 1,200 feet. Two hypotheses are advanced to account for the flows: (1) That they took place in Paleozoic times, perhaps Carboniferous, the lava being periodically poured out over the old sea bottoms; and (2) that the whole series of flows was contemporaneous, and in point of time post-Carboniferous. In this case the intercalations may be regarded as intrusive sheets, following the lines of least resistance and forcing themselves between the strata. Most probability seems to attach to the latter view.

Mr. Bain's paper deals with the distribution and relations of the St. Louis limestone in Mahaska county, where it is shown to have the same irregularity as to thickness and structure as it presents generally in Iowa. To explain the irregularity in the surface of this formation, appeal is made to erosion during Kaskaskia time, when Iowa was a land surface. This would imply a considerable elèvation in order to produce the carving, a conclusion not wholly free from doubt. In some localities a sandstone, treated as presumably belonging to the coal measures, rests upon the limestone.

The remaining paper, by Mr. Houser, is devoted to a discussion of some lime-burning dolomites, and dolomitic building stones from the Niagara.

C. H. GORDON.

THE MICROCOSM.

RELIEF MAPS AND MODELS.

Especial attention given to Relief Maps. All work of this kind executed accurately and artistically. Copies furnished of models made for the Government; Grand Cañon of the Colorado, Yosemite Valley, Wasatch and Uinta Mountains, Mt. Taylor, Mt. Shasta, Leadville, Eureka, Yellowstone National Park, etc., etc. Also model of the whole **United States,** with adjoining *Ocean bottoms, modeled on correct curvature.* Send for descriptive price list.

SYSTEMATIC COLLECTIONS.

With unusual facilities for securing educational materials, it is proposed to take the lead in furnishing systematic collections for teaching **Mineralogy, Geology,** and **Zoology** in Schools and Colleges. Individual specimens also furnished. Catalogue sent on receipt of 6 cents in postage stamps.

LANTERN SLIDES.

Series of Lantern Slides for class illustration in Geology, Physical Geography, etc.

METEORITES.

Write me if you have meteorites to sell, wish to buy, or have them cut and polished.

ANATOMICAL MODELS, TAXIDERMY, ETC.

☞ *Can furnish Dana's New System of Mineralogy for $10.00. Postpaid, $10.30.*
Send for Circular.

EDWIN E. HOWELL,
612 17th St., N. W., Washington, D. C.